AD-A009 354

GAS CONSUMPTION OF SCUBA DIVERS

M. W. Lippitt, Jr., et al

Naval Coastal Systems Laboratory
Panama City, Florida

October 1974

UNCLASSIFIED

SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

REPORT DOCUMENTATION PAGE

READ INSTRUCTIONS BEFORE COMPLETING FORM

1. REPORT NUMBER NCSL 223-74	2. GOVT ACCESSION NO.	3. RECIPIENT'S CATALOG NUMBER AD-A009 354
4. TITLE (and Subtitle) Gas Consumption of Scuba Divers		5. TYPE OF REPORT & PERIOD COVERED
		6. PERFORMING ORG. REPORT NUMBER
7. AUTHOR(s) M. W. Lippitt, Jr., and G. F. Bond, Capt., (MC), USN		8. CONTRACT OR GRANT NUMBER(s)
9. PERFORMING ORGANIZATION NAME AND ADDRESS Naval Coastal Systems Laboratory Panama City, FL 32401		10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS Prog. Element 62543N Task No. PO-4-0015-23
11. CONTROLLING OFFICE NAME AND ADDRESS Naval Coastal Systems Laboratory Panama City, FL 32401		12. REPORT DATE October 1974
		13. NUMBER OF PAGES 65
14. MONITORING AGENCY NAME & ADDRESS(if different from Controlling Office)		15. SECURITY CLASS. (of this report) UNCLASSIFIED
		15a. DECLASSIFICATION DOWNGRADING SCHEDULE

16. DISTRIBUTION STATEMENT (of this Report)

Approved for Public Release; Distribution Unlimited

17. DISTRIBUTION STATEMENT (of the abstract entered in Block 20, if different from Report)

18. SUPPLEMENTARY NOTES

19. KEY WORDS (Continue on reverse side if necessary and identify by block number)

Air Breathing	Underwater	Identifiers:
Scuba Divers	Swimmer Diver	Cold Water Diving
Breathing Apparatus	Hyprothermia	Open Circuit SCUBA
Stress (Physiology)	Exercise (Physiology)	Gas Consumption (Divers)
Low Temperature	Bioinstrumentation	

20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

A series of 6-hour test dives were accomplished to determine the gas consumption rates of divers breathing air from an open circuit demand system for rest, light exercise, and moderate exercise; at water temperatures of 40°F, 60°F and 80°F. Diver dress was the wet suit. The results indicate a significant increase in gas consumption in 40°F water for the rest and light exercise activities. The 40°F moderate exercise and all exercise levels at 60°F and 80°F produced values close to those predicted in the U.S. Navy Diving Gas Manual. Only two divers out of six were able to complete the 40°F, 6-hour dive.

TABLE OF CONTENTS

TABLE OF CONTENTS (CONT'D)

LIST OF ILLUSTRATIONS

LIST OF TABLES

INTRODUCTION

It has frequently been observed by experienced divers that predictions of the quantity of gas consumed on demand-type scuba in cold water is substantially lower than the amount actually used. The U.S. Navy Diving Gas Manual contains information for predicting gas consumption over a range of diver workloads and depths, but includes no consideration of the effect of cold water on gas consumption.

It is apparent that the ability to predict the amount of gas required for a particular mission would be desirable in many Naval diving operations and that, at times, it could be the critical factor in mission success and diver safety.

The experiments described in this report resulted from a request by the Naval Amphibious Forces to establish a test program to determine the relationships between water temperature, exercise level, dive duration, and gas consumption so that future predictions relative to diver gas consumption can be made more accurately.

While a considerable amount of data have been published on oxygen consumption at various workloads and water temperatures, no account could be found of specific gas consumption measurements in the range of interest.

The basic objective of the program was to obtain data useful in the prediction of the gas consumption rates of SEAL/UDT divers under conditions as close as possible to actual conditions of operation. Major constraints were the requirements for providing controlled water temperatures, and obtaining gas consumption and physiological data under imposed repeatable workloads. These constraints made it impractical to closely simulate actual missions, particularly as might relate to the psychological aspects of the experiment.

Initially it was intended to include depth as a variable and to perform the simulations in a hyperbaric facility. During the course of experiment design, this factor was eliminated from the current series to obtain a better statistical separation of the variables of greatest interest; i.e., water temperature, workload, and dive duration.

TEST OBJECTIVES

The objectives of the experiment were: (1) to determine the gas consumption rates for divers breathing air from an open circuit demand type of breathing apparatus for specific constraints of workload, water temperature, and duration of exposure, and (2) to incorporate the information obtained into a format optimized for use in operational planning.

METHODS AND MATERIALS

EXPERIMENT DESIGN

An Experiment Design Conference was conducted at NCSL on 9-10 October 1973 to discuss, plan, and design the test program. Dr. Paul Webb of Webb Associates, who has done a great deal of work in the fields of exercise and thermal physiology, was retained on contract to perform a design study and participate in the design conference. Also participating were Mr. W. T. Jenkins, Mr. Edward Sharp, the authors from NCSL, and the Task Sponsor, LCDR Clancy Hatleberg, COMPHIBAC. Discussions covered a wide range of operational, physiological, and safety considerations. Tables 1 and 2 present a summary of the test conditions and program.

Prior to commencing the tests, it was considered necessary to obtain certain anatomic and physiological values. Anthropomorphic values were deemed useful, because knowledge of the lean-fat ratio of each diver would aid in performance prediction, and would be useful in final data interpretation. Physiological values obtained for baseline recording included complete physical axaminations. ECG's, extensive pulmonary function studies, and a total of 19 separate determinations of blood morphology and blood chemistries.

In order to measure the effect of variations between divers, volunteers were graded according to their normal gas consumptions over the range of workloads and paired for the experiment. For example, diver A who used the most gas under normal conditions was paired with diver F who used the least. This pair was then exposed to identical test conditions. In a similar manner, pairs B and E, and C and D were identified (see Table 2).

The paired divers (three pairs) were combined with water temperature (40°F, 60°F, and 80°F) and exercise (rest, light, and moderate) to comprise the controlled parameters of the test. A balanced statistical test of divers/temperature/exercise parameters required 27 separate

(Text Continued on Page 5)

TABLE 1

TEST CONDITIONS SUMMARY

Controlled Variables

Water temperature - 40°F, 60°F, 80°

Workload - Rest, light (9 lb), Moderate (12 lb) (alternate work and rest during work tests)

Duration - 6 hours

Test Conditions

Breathing Gas - Air

Diver dress - Fabricated of neoprene without zippers; 1/4" thick Farmer John pants; 1/8" vest with hood; 1/4" jacket with hood; 1/4" soft soled boots; 3-fingered mittens, 3/8" with 1/4" over palm

Depth - Approximately 6 FSW

Water composition - Fresh

Independent Variables

Respiratory minute volume

Rectal temperature

Heart rate

Respiratory rate

Other Variables - Recorded

Gas manifold pressure

Gas temperature - Laminar flow element inlet

Water temperatures - 2 levels

Gas reservoir selected

Gas reservoir pressure and time

Barometric pressure

TABLE 2

TEST SCHEDULE

Dive	Divers	Workload	Water Temperatur (°F)
1	B & E	Moderate (12 lb)	60
2	A & F	Light (9 lb)	60
3	C & D	Rest	60
4	A & F	Rest	40
5	B & E	Light (9 lb)	40
6	C & D	Moderate (12 lb)	40
7	B & E	Rest	80
8	C & D	Light (9 lb)	80
9	A & F	Moderate (12 lb)	80

Hourly Exercise Schedule, Repeat Each Hour

Time (Min)	Activity
0	Both resting
10	Diver #1 start exercise
30	Diver #1 stop exercise Diver #2 start exercise
50	Diver #2 stop exercise
	Both rest

combinations. This, along with the 6-hour duration of each combination, represented an unfeasible test period due to fund and time restraints. The test was therefore designed around the three water temperatures and three exercise levels with diver pairs randomly selected; each pair would be subjected once to each water temperature and to each exercise. The test design used is depicted in Table 2. Variations due to divers could not separately be statistically analyzed, and would therefore be combined with test variation (standard error of estimate). The analysis of gas consumption data ($\hat{V}$) used a regression model when V equals predicted gas consumption.

$$\hat{V} = \beta_o + \beta_1 T + \beta_2 T^2 + \beta_3 t + \beta_4 t^2 + \beta_5 t^3 + \beta_5 W_1$$
$$+ \beta_5 W_2 + \beta_6 D_1 + \beta_7 D_2 + \ldots \beta_{10} D_5 + \beta_{11} TW_1$$
$$+ \beta_{12} TW_2 + \beta_{13} TD_1\ t + \ldots \beta_{17} TD_2 + \beta_{18} R_T$$
$$+ \beta_{19} Rt_1 + \ldots \beta_{23} Rt_5 .$$

Where T = water temperature (F)

t = time (minutes)

W = work level

D = divers

R_T = rectal temperature

β_i = regression coefficients -, i = 0, 1, 2, ..., 23.

This regression model includes the above controlled parameters along with physiological parameters monitored during the testing period along time-of-exposure. The physiological parameters are discussed later.

DIVER SAFETY

Considering the physical hazards imposed by these tests, it was deemed imperative that all important physiological parameters be closely monitored by a diving medical officer with experience in cold water diving. Accordingly, each 40°F and 60°F dive was continuously attended by a senior diving medical officer. Deep rectal temperatures were displayed and recorded every 45 seconds as a visual and pen-recorded event. In addition, a 2-lead electrocardiogram was constantly recorded, and the respiratory volume pattern was continuously presented for examination by the medical officer. Appropriate abort parameters were established prior to the test.

Because of the cumulative hazards inherent in these tests, considerable emphasis was placed on the safety aspects of the test procedures. As previously stated, conditions of the test were clearly outlined to the volunteer divers, and it was emphasized that any dive could be terminated when the diver felt that his physical condition dictated such an abort, or when the diving medical officer judged it necessary. The physiological monitoring system provided a continuous display of such vital signs as core temperature, electrocardiogram, heart rate, and respiratory pattern. In addition, the diver was under constant visual surveillance, and was frequently interrogated via underwater communications. Finally, a safety man was stationed at the top of the diving tank, and the diver was tethered with a safety retrieval line. Thus, it was believed that all necessary precautions were taken to assure the safety of the divers in the tests.

The following ground rules were adopted:

1. A physical examination would be performed on each diver prior to each dive.

2. Continuous monitoring and display of ECG and rectal temperature would be required for monitoring purposes.

3. A diving medical officer would be present at all times during the cold water (40°F and 60°F) dives.

4. Criteria for diver abort would include:

   a. Diver wishes to terminate.

   b. Diving medical officer decision.

   c. Rectal temperatures of 95°F or below.

   d. Heart rates of 160 beats per minute or above.

5. A safety tender would monitor diver activities in the test tank at all times.

6. Rewarm techniques would be required as directed by the diving medical officer and would be accomplished as follows:

   a. Diver will exit water, remove mask, swim fins, hookah harness, and be assisted to the rewarm area retaining the physiological instrumentation. This shall be done as quickly as possible.

b. A hose with flowing hot water (not to exceed 110°F) shall be inserted within the wet suit at the neck opening to flood the suit with hot water. Gloves and boots will be removed and a pan of warm water provided for the feet.

c. Hot drinks will be provided for the divers in whatever quantity they desire. Alcohol consumption by the rewarming divers will not be permitted.

c. Rectal temperature will be monitored and when the diving medical officer decides it has returned to an acceptable value, the rewarm will be terminated.

TEST FACILITY

The tests were conducted at the NCSL Hydrospace Laboratory in a test tank fabricated of 3-inch redwood. The tank measures 12 feet long, 8 feet wide, and 8 feet deep and is equipped with a chiller, heater, and a swimming pool filter system. Two metal chairs were provided for the diver's use during the rest portions of the protocol and the ergometer was adjusted so that the divers chest was at approximately the same depth (52 inches), whether swimming or sitting, to avoid different depth corrections when processing the gas comsumption data.

DIVER SELECTION AND PREPARATION

Six divers from the NCSL diving locker were selected to participate in the program. Five of the subjects were qualified SEAL or UDT divers and one a first class diver.

The divers were measured and custom fitted for special wet suits. These suits, which are the type worn during actual missions, are fabricated without zippers from foam neoprene and consist of: 1/4-inch thick Farmer John pants; 1/8-inch vest with hood; 1/4-inch jacket with hood; 1/4-inch soft soled boots; and 3-fingered mittens, 3/8 inch with 1/4 inch over palm. Each diver wore the face mask and swim fins he normally used.

Prior to the tests, anthropometric measurements including skin fold were made on each diver. These measurements were used to estimate percentage body fat which is presented in Table 3. In addition, pulmonary function and certain blood tests were performed.

(Text Continued on Page 9)

TABLE 3

DIVER ANTHROPOMETRIC MEASUREMENTS AND NORMAL GAS CONSUMPTION

Diver	Age	Weight (kg)	Height (cm)	Abdominal Circumference (cm)	Lean Body Weight* (kg)	% Fat	Relative Gas Consumption (cfm)		
							Rest	Light Exercise	Moderate Exercise
A	31	95.2	185.4	97.2	74.9	21	0.39	1.6	1.8
B	32	93.0	182.9	95.9	73.4	21	0.36	1.1	1.6
C	31	69.9	160.6	80.0	60.0	14	0.30	1.0	1.4
D	32	92.0	183.5	93.5	74.1	19	0.35	0.99	1.3
E	24	77.6	177.8	80.0	68.1	12	0.35	0.95	1.2
F	26	77.5	170.8	88.5	62.3	20	0.32	0.74	1.0

*Lean body weight (kg) = 40.99 + 1.0435 x weight (kg) - 0.6734 abdominal circumference (cm)

From: Wright, H. F., and Wilmore, J. H., *Estimation of Relative Body Fat and Lean Body Weight in a U.S. Marine Corps Population*, Aerospace Medicine, v. 45, p. 231-240, March 1974.

Each diver was exposed to the three workloads for a short training dive with the water temperature at approximately 75^{o}F to establish his normal gas consumption. Respiratory minute volumes were obtained for 10 minutes at each exercise level and the values, recorded after equilibrium was reached, were averaged. The results are presented in Table 3. It is interesting to note that the divers had the same ranking for both light and moderate exercise. The rest values were all very close together. Each diver was asked to comment on how well his relative rank matched his own experience as to the gas he normally consumed compared to that used by others; they agreed with the ranking order.

The divers were urged to consume a hearty breakfast containing a maximum of fat prior to the 40^{o}F and 60^{o}F dives. Special arrangements were made to facilitate this at the EM mess. The divers were also urged to obtain adequate rest on the preceding night.

EQUIPMENT

<u>Gas Supply and Measurement System</u> (Figure 1)

Compressed air was supplied to reservoirs 1 and 2 which were alternately used to supply breathing air and recharged. The water volumes of these vessels were accurately measured and the amount of gas used during a particular period calculated by noting the times and the pressures when the reservoir was connected and disconnected. This measurement serves as a check on the primary gas consumption measurement system.

The supply from the reservoir selected is connected to a large dome regulator which is controlled by a dome-loading regulator operated from a nitrogen pressure source. A high capacity regulator (369 cfm) in conjunction with a 180-cubic foot nitrogen cylinder were found to be necessary to maintain the manifold pressure constant to within $\pm$ 1 psi at 125 psi during the high flow rates encountered at the beginning of inspiration through the demand regulator. A gas temperature probe is located in the manifold before it bifurcates to supply the laminar flow elements (LFE) for the measurement of each diver's gas flow. The differential pressure across each LFE is measured by $\pm$ 0.1 psid variable reluctance pressure transducer, and is used as the uncorrected flow (V) signal for each diver. Gas to each diver passes through the LFE, through a checkvalve to isolate each system, and through a 40-foot coil of copper tubing immersed in the test tank to ensure that the gas is at water temperature. A 12-foot hose supplies this gas to the diver's hookah harness which is equipped with a second stage Conshelf 12 regulator and hose.

(Text Continued on Page 11)

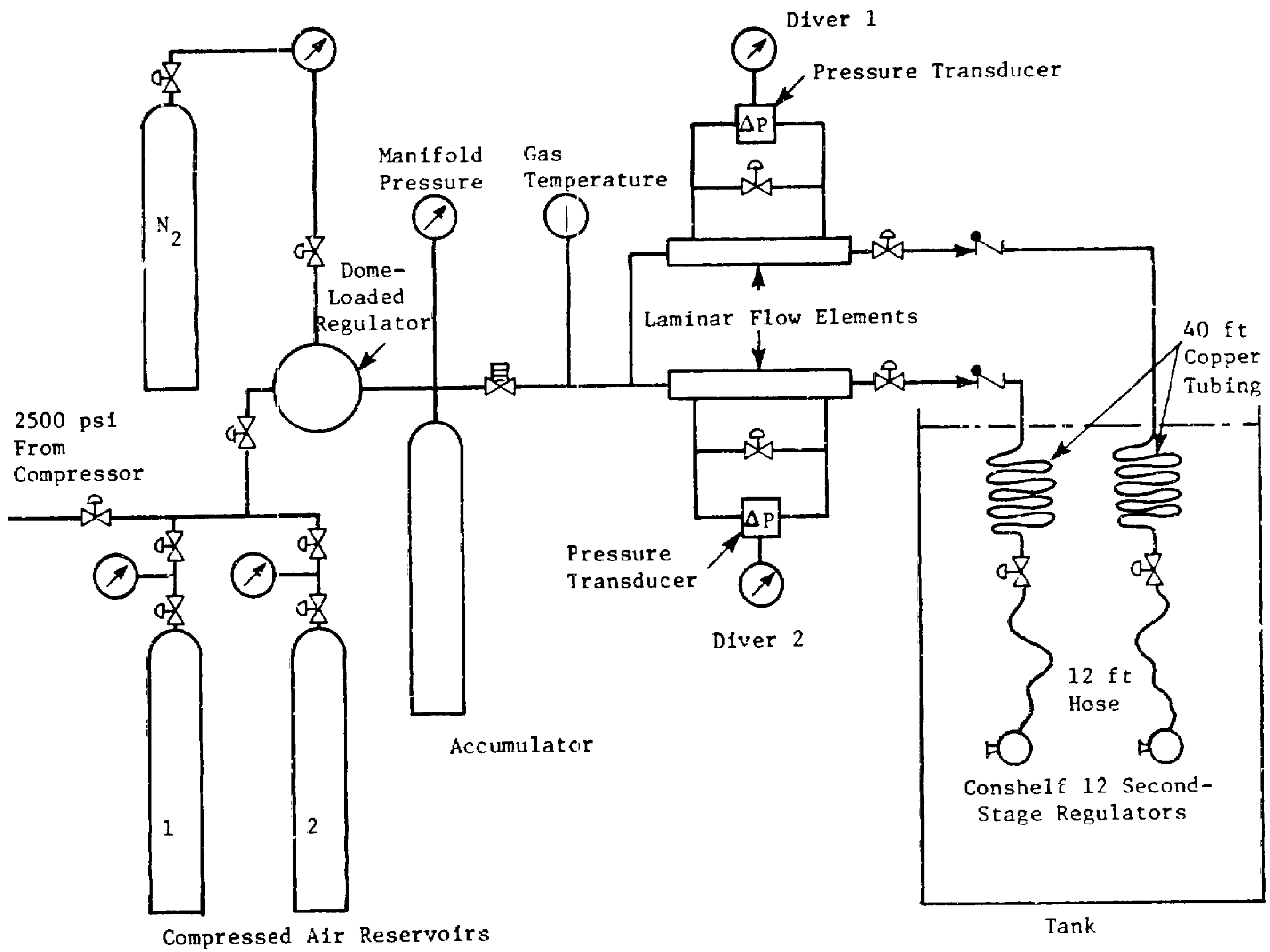

FIGURE 1. GAS SUPPLY SCHEMATIC AND MEASUREMENT SYSTEM

Physiological Measurements (Figures 2, 3, 4).

In addition to the inspired flow measurements discussed above, from which respiratory minute volumes were obtained, an electrocardiogram and rectal temperature were required for safety monitoring and data. A respiratory waveform was obtained by impedance pneumography. These measurements were accomplished using NASA APOLLO and GEMINI signal conditioners. The signal conditioners were assembled in a small aluminum box, with the umbilical cable, bio-sensor harness, and rectal probe attached, and potted with silicone rubber to prevent the entry of water. In use, the electrodes were attached to the diver, the rectal probe was inserted 10 cm beyond the anal verge, and the box and coiled umbilical cable were pulled through a slit in the wet suit jacket during the donning procedure. When the diver completed dressing, the slit was closed with nylon thread and glue, and the signal conditioner box was secured to the chest with elastic bandages. After the diver donned the hookah harness, the umbilical was taped to the air supply hose and connected to the biomedical junction box above the test tank. Electroshock safety was provided by matched 100K ohm resistors in series with the two ECG electrodes and the ground electrode. These resistors were mounted in the sensor harness. The $\pm$ 10 vdc power supply for the signal conditioners and the strip chart recorder for physiological data display were connected to the ac line through a 0.75-milliampere ground fault interrupter. Power to all other test instrumentation was supplied through 5-milliampere ground fault interrupters.

Exercise Ergometer

An ergometer was designed and fabricated which allowed the diver to swim naturally against a constant force to simulate, as closely as possible, the work required to swim against a 0.5- and 1.0-knot current. Since the diver was unable to use the planing forces derived from his motion through the water to maintain his attitude, a force table ergometer was designed (Figure 5). The diver lies on the sled with his shoulders in the curved restraints and swims against the force of the weight selected. The diver must be negatively buoyant and equipped with 1.5- to 2-pound ankle weights to counteract the buoyancy of the wet suit pants. Workloads simulating 0.5- and 1.0-knot swims were selected for the light and moderate exercises, and weights providing forces of 9 and 3 pounds were fabricated. For light exercise, the 9-pound weight alone was used; for moderate exercise, both were used. The stainless steel cable supporting the weights was painted red 2 inches from each end and green for 14 inches in the center. The cable passes out of the pulley within easy view of the diver who was instructed to keep the green portion of the cable at the pulley. This ensured that the sled was not against either stop and that the correct load was being applied. The diver could allow the sled to move back and forth 14 inches and still be in the green. Comments from the divers and other divers evaluating the ergometer indicated that the exercise seemed to be quite similar to swimming against currents of 0.5- and 1.0-knot.

(Text Continued on Page 16)

FIGURE 2. HEART RATE AND RECTAL TEMPERATURE INSTRUMENTATION

FIGURE 3. DIVER DRESSING - SIGNAL CONDITIONER BOX

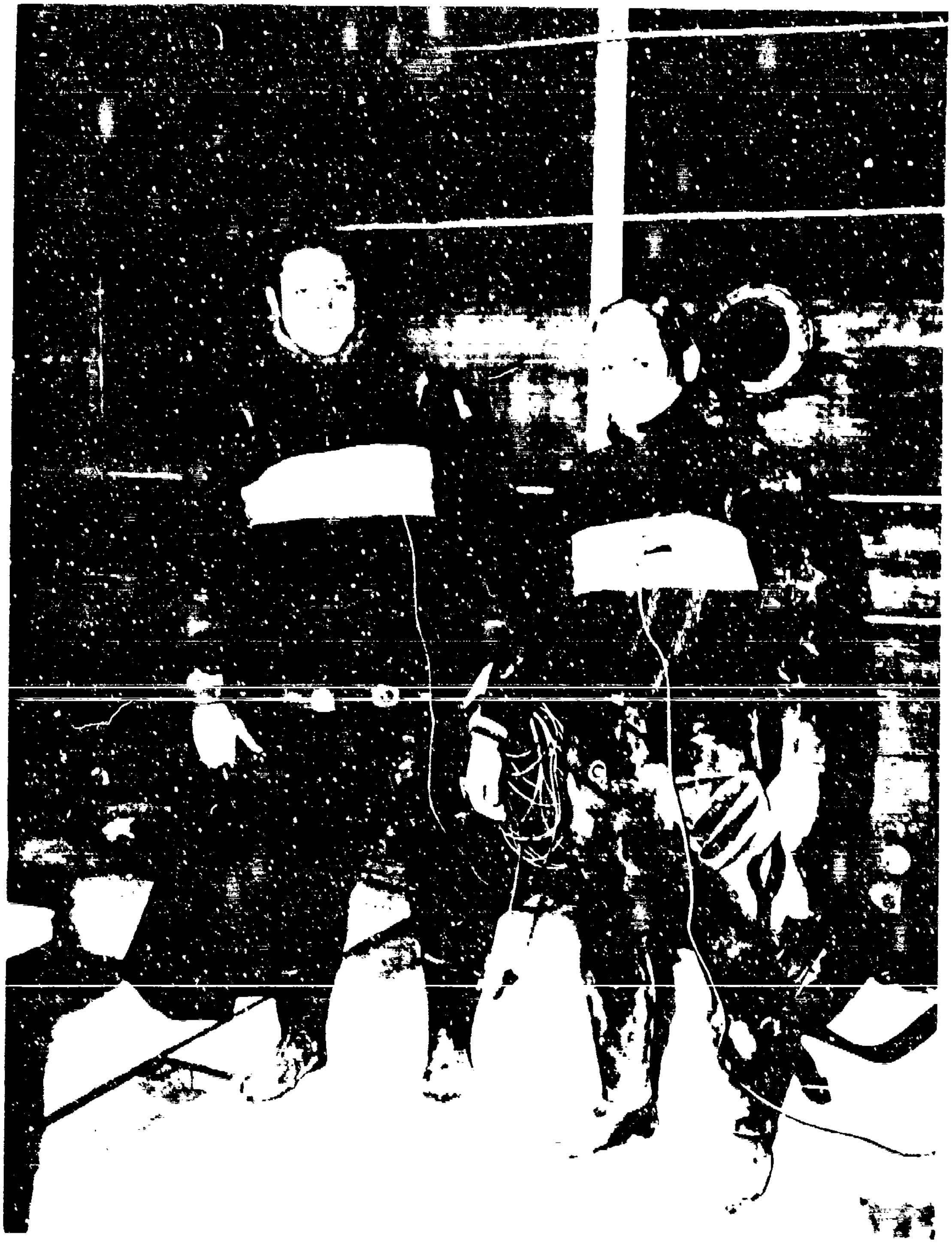

FIGURE 4. INSTRUMENTED DIVERS READY FOR DIVE

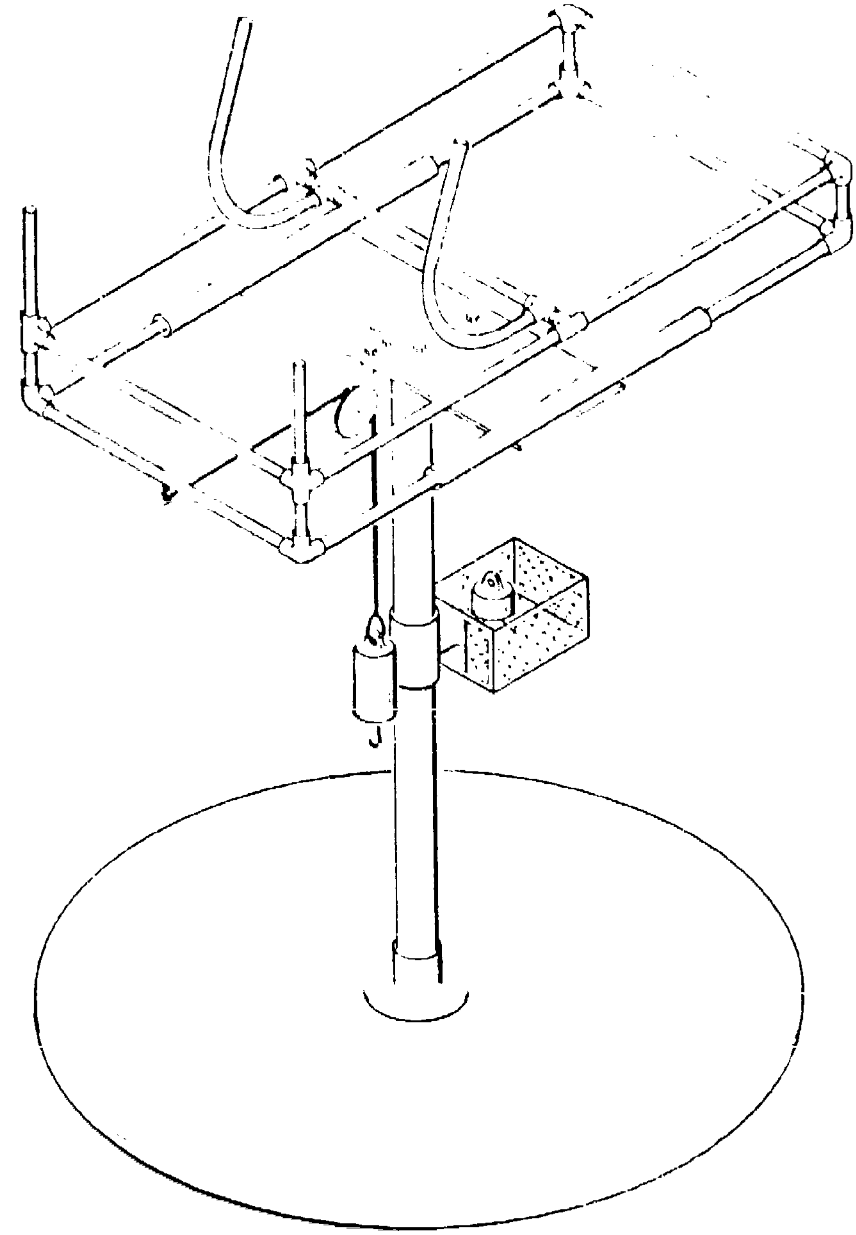

FIGURE 5. DIVER'S ERGOMETER

Data Recording and Display System

Test data were recorded on a 14-channel magnetic tape recorder for subsequent analysis. Displays included a 6-channel strip chart recorder for ECG, respiratory waveform, and respiratory flow ($\dot{V}$) from each diver. The rectal temperatures were displayed on digital meters. For "quick look" gas consumption data, the $\dot{V}$ signals from the two divers were processed by respiratory integrators which reset every minute yielding a respiratory minute volume each minute. The integrator outputs were displayed and recorded on a 2-channel strip chart recorder. Reservoir pressures and manifold pressure readings were obtained from the gauges and recorded in the log every 15 minutes. Manifold gas temperature, and the top and bottom water temperatures were measured by thermocouples and logged in a like manner.

Calibration

The individual pressure gauges and transducers were calibrated against laboratory standards as were the temperature measuring probes. Prior to and after each dive, each data channel was shorted and then stimulated with a calibration voltage signal. A system calibration of the gas flow ($\dot{V}$) channels was accomplished by attaching a scuba regulator equipped with a 1-liter syringe to each diver's gas supply hose and withdrawing ten 1-liter volumes. Considerable problems were experienced until it was determined that the exhaust valve on the regulator was leaking air. When the check valve was secured with tape and a Collins respiratory valve inserted to vent the expired gas, the consistency of the data was markedly improved but care was still necessary to avoid operating the syringe plunger too rapidly. The $\dot{V}$ pressure transducer outputs resulting from the above procedure were used to calibrate the respiratory integrators and as a $\dot{V}$ calibration signal on the recorded $\dot{V}$ data.

DATA REDUCTION AND ANALYSIS

During each dive, the signals from the differential pressure transducers across each diver's laminar flow element (LFE) were recorded on magnetic tape. The signals from the heart rate computers, which were driven by the ECG signals, were also recorded together with the outputs from the rectal temperature measuring systems. From the nine dives, approximately 54 hours of data were recorded. The three quantities of of interest; i.e., respiratory flow ($\dot{V}$), heart rate (HR), and rectal temperature (T_R), were derived from the raw data as follows:

1. The analog data tapes were digitized with the $\dot{V}$ being sampled 16 times per second, and the T_R and HR at 4 times per second. The $\dot{V}$ was sampled more frequently to permit good resolution of the respiratory waveform.

2. The digitized differential pressures corresponding to $\dot{V}$ were converted to flow by use of the LFE calibration curves and then corrected for LFE inlet temperature and pressure. This process produces $\dot{V}$ in standard cubic feet per minute. The diver, however, was at a depth of 52 inches and consuming gas at the temperature of the water, so that his actual respiratory flow differs from the flow in scfm. Because the gas consumption data from this experiment are intended for use during operational dives, the flow data were further manipulated to convert to the actual flow to the diver as if he were at standard conditions; i.e., $70^{\circ}F$ and 29.92 inches of mercury.

3. The corrected $\dot{V}$ data were integrated for 60 seconds and divided by the number of samples per minute (60 by 16) to obtain minute volumes for each diver. These data are plotted versus time in Appendix A.

4. The minute volumes were averaged over the exercise and rest portions of each hour so that exercise and rest gas consumption rates for each hour were obtained for each diver. One rate per hour was obtained for the three rest dives. The quantities thus obtained are the basis for the statistical manipulations described in the section on RESULTS.

5. The T_R and HR signals were processed by the application of the calibration data and plotted versus time. Averages were derived over the same rest and exercise periods as for the $\dot{V}$ data to yield hourly quantities for entry into the statistical program.

TEST DIVES

GENERAL

The dives were started on 5 April 1974 and continued each work day until 17 April 1974. The daily schedule is presented below.

Daily Schedule

0800	System checkout - start
0815	Divers arrive for medical check
0830	Divers instrumentation and dressing - start
0830	Tape recorder calibration
0900	Test starts; divers enter water
1500	Divers exit water; start rewarming procedure
1515	Initiate post-test calibrations; remove sensor harnesses; clean electrodes and probes ready for next dive
1530	Secure system.

The time each diver completed in each test is illustrated in Figure 6.

DIVE 1

Conditions: Divers B and E in wet suits, 60°F water temperature, moderate exercise

During the first 10 minutes, the divers surfaced to obtain additional weights and Diver E was provided with ankle weights to counteract the buoyancy of the wet suit pants. Diver B requested additional weights after his first exercise period. During the fourth exercise period, Diver E surfaced to comment that water was entering his suit through the slit made to allow the passage of the physiological instrumentation box. Additional elastic bandages were applied and nylon thread was used to secure the slit on subsequent dives. No shivering was reported by the divers during the dive. Rewarm was performed on both divers.

This dive was the first time that the custom-fitted SDV wet suits were used and the extremely tight fit across the chest area coupled motion artifact into the ECG signal and produced periods of extremely noisy ECG data. The heart rate processors were frequently unable to obtain a valid heart rate determination. During the dive, the ECG's from the divers were displayed on a variable persistance oscilloscope and the complexes visually counted. In this way, a heart rate could usually be obtained from the noisy ECG and noted in the test log every 15 to 30 minutes. Where the magnetic tape data were found to be unusable, the heart rate determinations from the test log were used.

DIVE 2

Conditions: Divers A and E in SDV wet suits, 60° water temperature, light exercise

No shivering was reported. The use of nylon thread and neoprene glue to close the slit in the wet suit worked satisfactorily. Rewarm was performed on both divers.

Donut-shaped pieces of vinyl foam were placed over the ECG electrodes in an attempt to reduce the artifact in the ECG signals. These helped to some extent and were used on subsequent dives; however, no adequate method of fastening them to the diver's chest was achieved. During some of the dives, suit flexing due to exercise would cause the foam pad surrounding the top sternal electrode to migrate so that its edge contacted the electrode. When this happened, the artifact became

(Text Continued on Page 20)

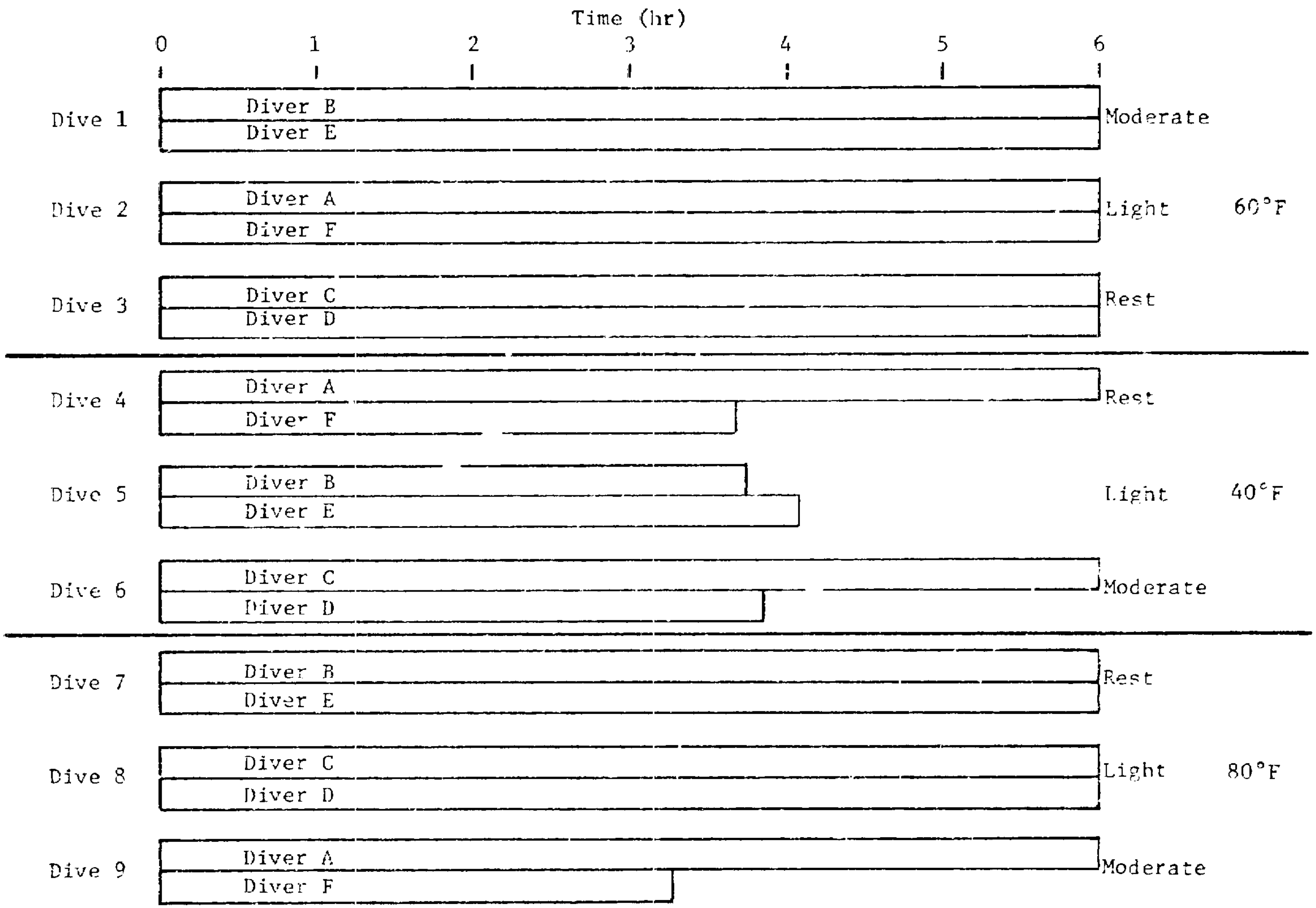

FIGURE 6. DIVER TEST TIME

so extreme that heart rate was often impossible to determine during exercise. It is believed that this problem can be easily resolved, but the daily dive schedule did not allow the time to explore possible solutions.

DIVE 3

Conditions: Divers C and D in SDV wet suits, 60°F water temperature, rest

After 120 minutes, divers admit to some shivering and write, "It's cold," on message board. At 240 minutes, Diver C was not shivering and Diver D indicated that he was shivering slightly. During the fifth hour, it was found that the tape recorder was not operating and about 30 minutes of data were lost. Rewarm was performed on both divers and no drop in rectal temperature occurred during rewarm.

DIVE 4

Conditions: Divers A and F in SDV wet suits, 40°F water temperature, rest

After 45 minutes, it was discovered that Diver A was wearing a 3/16-inch wet suit vest in addition to the standard wet suit. He was brought to the surface and the vest removed. At 53 minutes, Diver A reported he was shivering slightly. At 75 minutes, both divers were shivering. After 221 minutes, Diver F voluntarily terminated, commenting that he had lost all sensation in his legs from the knees down. Upon rewarm, his feet became blue-purple and he complained of intense itching. At 260 minutes, Diver A reported normal sensation in all extremities. Diver A completed the 360 minutes and an uneventful rewarm.

DIVE 5

Conditions: Divers B and E in SDV wet suits, 40°F water temperature, light exercise

After 73 minutes, Diver E surfaced to complain of a severe headache. He was reassured by the medical officer and descended to continue the dive. At 175 minutes, Diver B surfaced to complain of having cold feet. Diver B again surfaced at 182 minutes to complain that his feet hurt due to the excessive tightness of his swim fins. Another set of fins was obtained and donned. At 225 minutes, Diver B voluntarily terminated due to extremely cold feet and started the rewarm. At 245 minutes, Diver E terminated stating that he was dizzy, nauseated, had a severe headache, and was afraid he was about to lose consciousness. The rewarm was started at once.

DIVE 6

Conditions: Divers C and D in SDV wet suits, 40°F water temperature, moderate exercise

Diver C's rectal temperature system failed just prior to entry into the water. Diver D started on time and Diver C was delayed 45 minutes to allow the change to the backup physiological monitoring package which involved removing the wet suit. At 230 minutes, Diver D voluntarily terminated, complaining of a feeling of pressure behind the ear. Rewarm was started. At 271 minutes, Diver C complained of leg cramps but no other symptom. Diver C completed the dive at 405 minutes. His actual time in the water was 360 minutes. Rewarm was satisfactorily completed.

DIVE 7

Conditions: Divers B and E in regular 1/4-inch wet suits with 3/16-inch vests, 80°F water temperature, rest

Entry of water into the physiological monitoring package caused the loss of rectal temperature data on Diver B. Periodic oral temperatures were obtained for safety monitoring purposes. No rewarm was required.

DIVE 8

Conditions: Divers C and D. Diver C wore 3/16-inch vest with 1/4-inch jacket with hood (no pants); Diver D wore 1/4-inch Farmer John pants with 3/16-inch vest with hood (no sleeves). 80°F water temperature, light exercise

During the first two exercise periods, the gas consumption rates did not show the expected regular increase during exercise. The reason for this became evident at 113 minutes when one diver surfaced to say that the ergometer was not working. The ergometer was removed from the tank; it was difficult to move the sled on the runners. When the bearings were flushed and lubricant spray applied, the almost friction-free operation was restored. Corrosion from the aluminum sled had probably fouled the bearings. The ergometer was returned to the tank with no further problems and the gas consumption rates resumed their normal variation. During the latter portion of the dive, the rectal temperature of Diver C was observed to fall slowly and he was brought to the surface for an oral temperature check. He did not admit to being cold or to any other symptoms. At the end of the dive, he was rewarmed and when he undressed, he commented that the rectal probe was not inserted as far as the tape wrap. This is believed to account for the unusually low rectal temperature readings.

DIVE 9

Conditions: Divers A and F in SDV pants and 1/4-inch wet suit jacket with hood, 80°F water temperature, moderate exercise

During the first 14 minutes, both divers worked on adjusting the ergometer. Diver A started the first exercise period at 15 minutes and Diver F at 35 minutes, both exercising for 20 minutes. During the second hour, an additional diver took underwater photographs of the equipment and divers. At 138 minutes, the gas supply manifold pressure was observed to have fallen to under 40 psi. This was corrected immediately but produced erroneously high gas consumption rates for approximately 5 minutes. At 170 minutes, Diver F was observed to have a heart rate of 133 bpm while exercising. This increased to 168 bpm during the last minute of exercise, and he was brought to the surface for examination. Diver F complained of feeling badly, but had no specific ailments. Blood pressure was 142/80 mm Hg and oral temperature was 97.2°F. Diver F's dive was terminated by the medical officer. Diver A completed the dive uneventfully.

RESULTS

GAS CONSUMPTION

General

The plots of the diver gas consumption rates versus time are presented in Appendix A. Surface intervals can be seen where the gas consumption falls to zero. It will be noted that the total dive time did not quite extend to 360 minutes (6 hours) in most of the plots. This time error was caused by a small difference between the tape speed during recording and playback, and does not materially affect the accuracy of the reduced data. Striking features of these plots are the variability from minute to minute in the gas consumption rates, and the reproducible increases caused by the periodic exercise.

In the following discussion the gas consumption rates observed are compared with the rates found in the U.S. Navy Diving Gas Manual for the appropriate workload. Refer to Figure 7 (note that water temperature is not a factor in this figure). These predicted rates are:

Rest - 0.28 scfm

0.5-knot swim - 0.64 scfm

1.0-knot swim - 1.4 scfm .

It should be recognized that the results obtained are predicated on a rather small data base, due to the limitation imposed by six divers and nine dives. This effect is exaggerated in the 40°F results where only two of the six divers continued past the fourth hour. In this case, data from six divers were obtained through the fourth hour, and from two for the fifth and sixth for rest. For the light exercise, values were obtained for two divers for three hours, and from one for the fourth. The moderate exercise is similar but with one diver finishing the test.

Analysis

Hourly averages were obtained for rest and exercise for each of six divers as described in subsection Data Reduction and Analysis. These averages are tabulated, for water temperatures of 40°, 60°, and 80°F in Tables 4, 5, and 6, respectively, and are plotted as a function of time in Figures 8, 9, and 10.

An analysis of variance was conducted on the test data presented in the tables. The controlled variables for this analysis were water temperature, exercise, and time (duration). Six divers were used in the tests as described in Experiment Design and Table 2. Since all divers were not used in all combinations of water temperature and exercise, the variability in gas consumption due to divers was treated as experimental error.

The analysis revealed, first of all, that gas consumption between exercise periods was statistically significant. The analysis also showed that gas consumption due to changing water temperature was statistically significant; that there was a significant interaction between exercise and water temperature; and that the difference in gas consumption due to time was significant. (All significant computations were at the 95 percent level of confidence.)

The difference between exercise levels was, of course, expected. The difference between gas consumption at different water temperatures was caused primarily by the lower consumption rate in 60°F water for all

(Text Continued on Page 31)

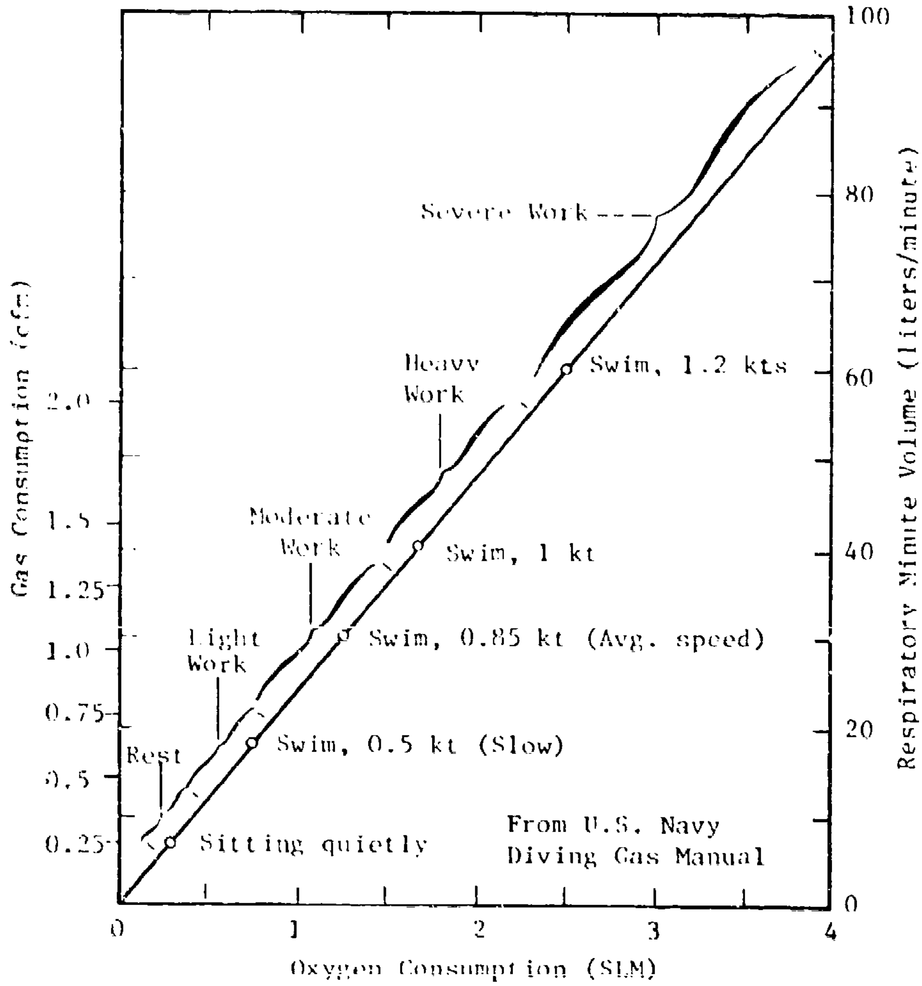

FIGURE 7. RELATION OF RESPIRATORY VOLUME AND OXYGEN CONSUMPTION TO TYPE AND LEVEL OF EXERTION

TABLE 4

HOURLY GAS CONSUMPTION AVERAGES IN 40°F WATER

Dive IV		
	Robinson (A) Diver 1	McCormack (F) Diver 2
Hour	Rest (cfm)	Rest (cfm)
1	0.472	0.422
2	0.561	0.460
3	0.662	0.523
4	0.623	0.45
5	0.586	-
6	0.640	-

Dive V				
	Cole (B) Diver 1		Davis (E) Diver 2	
Hour	Rest (cfm)	Light Ex. (cfm)	Rest (cfm)	Light Ex. (cfm)
1	0.326	0.50	0.338	0.618
2	0.340	0.493	0.507	0.704
3	0.371	0.612	0.494	0.681
4	0.352	0.748	0.584	0.524*
5	-	-	-	-
6	-	-	-	-

*Not valid.

Dive VI				
	Ross (C) Diver 1		Findlay (D) Diver 2	
Hour	Rest (cfm)	Mod Ex. (cfm)	Rest (cfm)	Mod Ex. (cfm)
1	0.439	1.00	0.366	0.944
2	0.451	1.01	0.374	0.869
3	0.450	0.988	0.473	0.904
4	0.504	1.06	0.493	0.918
5	0.550	0.91	-	-
6	0.612	1.12	-	-

Averaged Over Divers for all 40°F Dives			
Hour	Rest (cfm)	Light Ex. (cfm)	Mod Ex. (cfm)
1	0.394	0.559	0.972
2	0.448	0.598	0.939
3	0.495	0.646	0.946
4	0.501	0.748	0.989
5	0.568	-	0.91
6	0.626	-	1.12

TABLE 5

HOURLY GAS CONSUMPTION AVERAGES IN 60°F WATER

	Dive I			
	Cole (B) Diver 1		Davis (E) Diver 2	
Hour	Rest (cfm)	Mod Ex. (cfm)	Rest (cfm)	Mod Ex. (cfm)
1	0.435	0.989	0.315	0.621
2	0.399	0.828	0.261	0.689
3	0.377	0.733	0.238	0.701
4	0.360	0.773	0.263	0.620
5	0.377	0.686	0.286	0.640
6	0.376	0.650*	0.250	0.652

*Corrected Point

	Dive II			
	Robinson (A) Diver 1		McCormack (F) Diver 2	
Hour	Rest (cfm)	Light Ex. (cfm)	Rest (cfm)	Light Ex. (cfm)
1	0.353	0.90	0.209	0.52
2	0.354	0.85	0.146	0.48
3	0.385	0.80	0.194	0.45
4	0.370	0.85	0.146	0.48
5	0.292	0.80	0.151	0.45
6	0.290	0.85	0.152	0.53

	Dive III	
	Ross (C) Diver 1	Findlay (D) Diver 2
Hour	Rest (cfm)	Rest (cfm)
1	0.281	0.305
2	0.268	0.321
3	0.295	0.285
4	0.327	0.280
5	0.269	0.233
6	0.269	0.115

	Averaged Over Divers for all 60°F Dives		
Hour	Rest (cfm)	Light Ex. (cfm)	Mod Ex. (cfm)
1	0.316	0.71	0.805
2	0.291	0.66	0.758
3	0.296	0.62	0.727
4	0.291	0.66	0.696
5	0.268	0.62	0.663
6	0.250	0.69	0.651

TABLE 6

HOURLY GAS CONSUMPTION AVERAGES IN 80°F WATER

	Dive VII			Dive VIII			
	Cole (B) Diver 1	Davis (E) Diver 2		Ross (C) Diver 1		Findlay (D) Diver 2	
Hour	Rest (cfm)	Rest (cfm)	Hour	Rest (cfm)	Light Ex. (cfm)	Rest (cfm)	Light Ex. (cfm)
1	0.320	0.273	1	0.250	-	0.419	-
2	0.262	0.236	2	0.228	-	0.281	-
3	0.225	0.193	3	0.225	0.75	0.267	0.747
4	0.224	0.213	4	0.246	0.798	0.266	0.72
5	0.206	0.196	5	0.256	0.649	0.28	0.70
6	0.313	0.240	6	0.341	0.873	0.250	0.70

	Dive IX					Averaged Over Divers for all 80°F Dives		
	Robinson (A) Diver 1		McCormack (F) Diver 2					
Hour	Rest (cfm)	Mod Ex. (cfm)	Rest (cfm)	Mod Ex. (cfm)	Hour	Rest (cfm)	Light Ex. (cfm)	Mod Ex. (cfm)
1	0.380	1.09	0.276	0.763	1	0.319	-	0.93
2	0.390	0.935	0.219	0.974	2	0.269	-	0.95
3	0.386	1.20	0.22	0.744	3	0.252	0.75	0.97
4	0.346	1.11	-	-	4	0.259	0.76	1.11
5	0.336	0.907	-	-	5	0.254	0.67	0.91
6	0.323	0.969	-	-	6	0.293	0.79	0.97

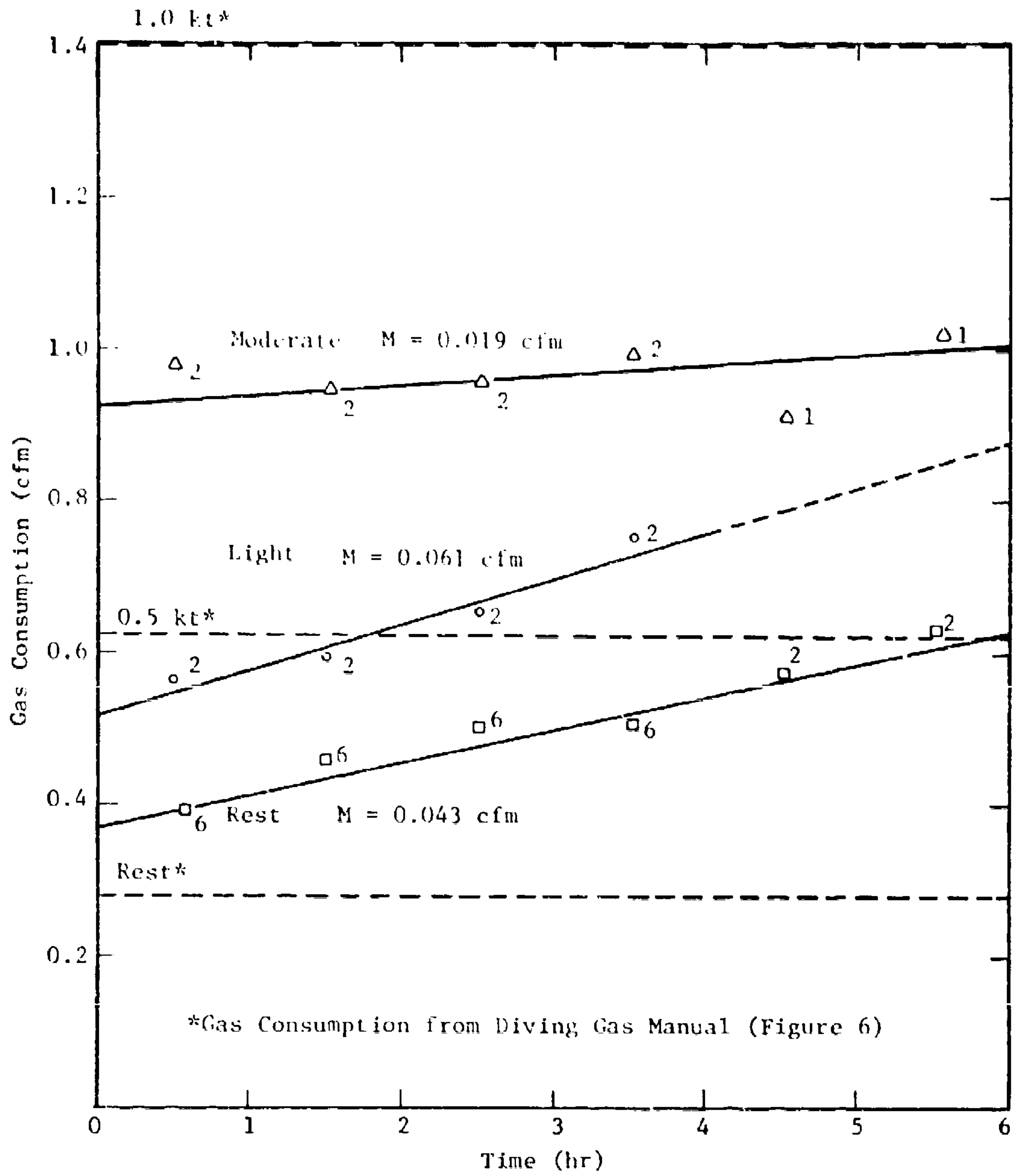

FIGURE 8. GAS CONSUMPTION VERSUS TIME IN 40°F WATER

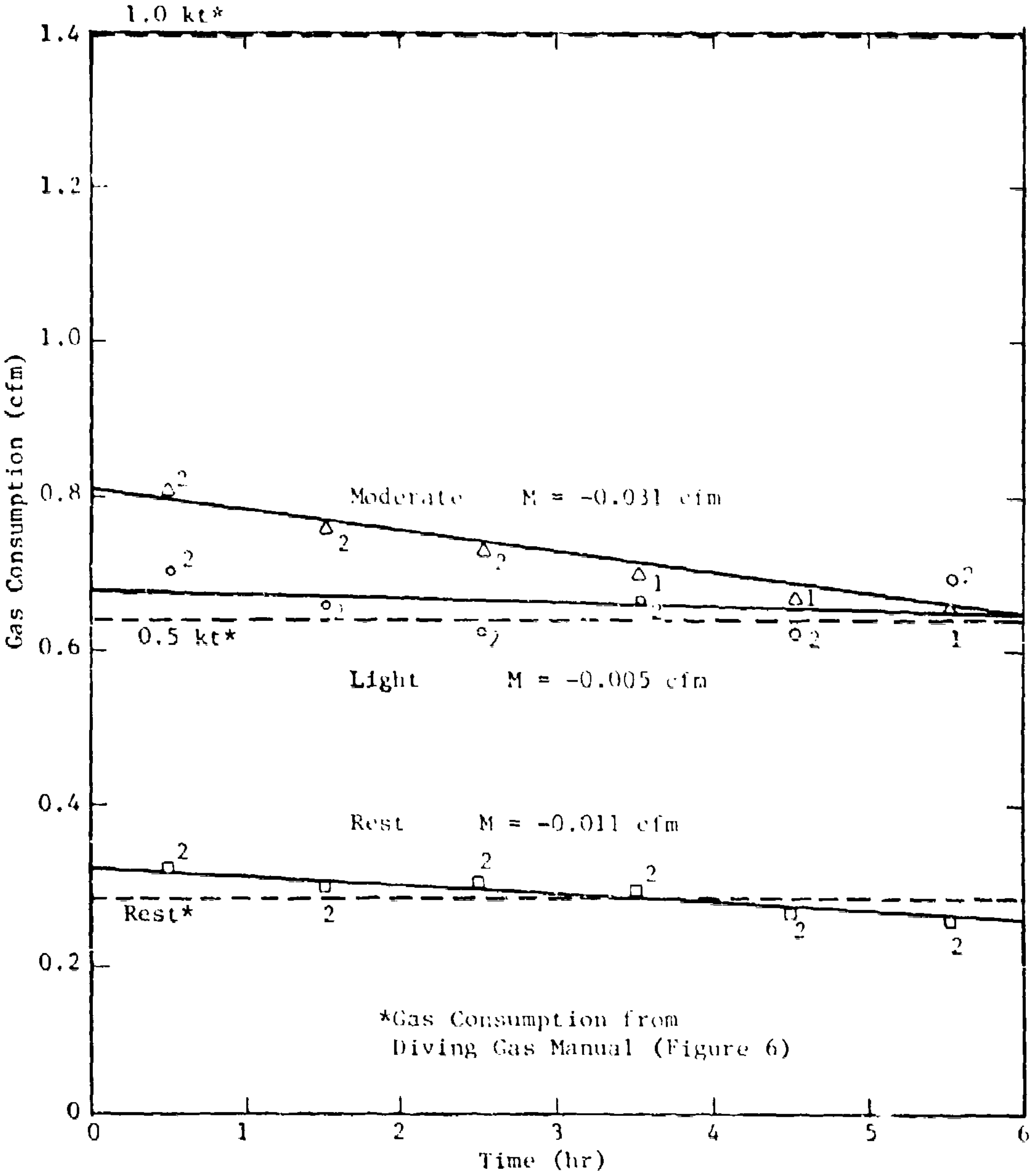

FIGURE 9. GAS CONSUMPTION VERSUS TIME IN 60°F WATER

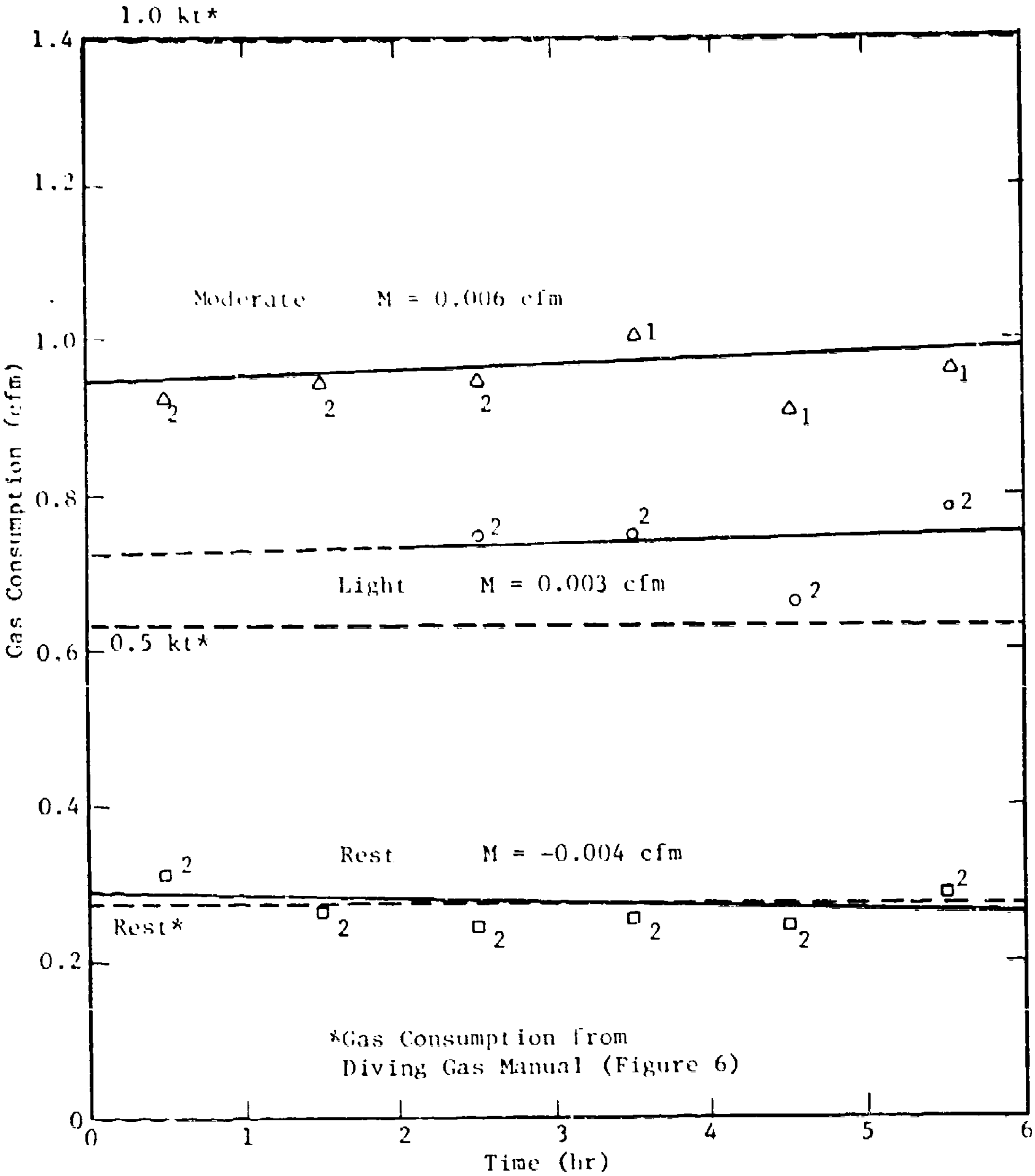

FIGURE 10. GAS CONSUMPTION VERSUS TIME IN 80°F WATER

three exercise levels. The cause of the difference due to time was the interaction between exercise and water temperature. This interaction was caused by (for all three exercise levels) the positive rate of change in 40°F water and the negative rate of change in 60°F water. The rate of change in consumption rate with respect to time in 80°F water was positive at light and moderate exercise, and negative at rest (Figures 8, 9, and 10). Due to this negative and positive slope in gas consumption as a function of time, a linear, least squares regression curve was obtained for combinations of water temperature and exercise level data. The form of this equation is

$$\dot{V} = \beta_o + \beta_1 \cdot t \text{ (hrs)}$$

where t = time.

These regression curves are plotted against the data in Figures 8, 9, and 10. The slope (M) is annotated on each plot along side the appropriate regression curve. This slope was tested against a slope of "0" to aid in determining if the inclination or declination was basically a function of time or if the slope could be attributed to experimental error. These findings are presented in Table 7. (Statistical significance means that the difference is real as opposed to chance.)

The test results were also compared, statistically, with gas consumption rates obtained from the U.S. Navy Diving Gas Manual (Figure 2). This analysis showed:

1. The at-rest test consumption rate in 60°F and 80°F water compared favorably with at-rest consumption rate from the diving gas manual. The at-rest test consumption rate in 40°F water was higher than the rate in the manual. (The manual consumption rate does not give a break-down by water temperature nor duration.)

2. The consumption rate for light work in 60°F and 80°F water compares with the rate from the manual for a 0.5-knot swim, but the gas consumption in the tests in 40° water was higher than the rate shown in the manual.

3. The moderate workload test consumption rate in 40°, 60°, and 80°F water was significantly below the rate shown in the manual for a 1-knot swim. Either the stress used to create the moderate workload did not simulate a 1-knot swim or the diving manual rate is high.

a. <u>40°F Dives</u>

(1) The rest values increase from approximately 140 percent predicted from the Manual to almost 230 percent predicted. This increase is seen on all of the divers at 40°F. A slope (M) of + 0.043 cfm

TABLE 7

COMPARISON OF THE SLOPE OF GAS CONSUMPTION RATE DURING TESTS WITH A SLOPE OF "0"

Test Condition Comparison	Slope Magnitude	Statistical Significance (95% level of confidence)
40° Water		
Rest	+ 0.043 cfm/hr.	Yes
Light Workload	+ 0.061 cfm/hr.	Yes
Moderate Workload	+ 0.019 cfm/hr.	Yes
60° Water		
Rest	- 0.011 cfm/hr.	No
Light Workload	- 0.005 cfm/hr.	No
Moderate Workload	- 0.031 cfm/hr.	Yes
80° Water		
Rest	- 0.004 cfm/hr.	No
Light Workload	+ 0.003 cfm/hr.	No
Moderate Workload	- 0.006 cfm/hr.	No

per hour is observed, and the divers are using approximately 1.7 times as much gas during the sixth hour as they were during the first.

(2) The light exercise values start somewhat below predicted, but show a slope of + 0.061 cfm per hour. It appears that this test was more difficult than the others with no one finishing. Diver B voluntarily terminated his dive due to extremely cold feet at the end of 3 hours and 45 minutes. Diver E terminated his dive shortly after the end of the fourth hour suffering from dizziness and nausea.

(3) It is obvious from all of the moderate exercise data that the 12-pound thrust used for this stress was not comparable to the 1.0 knot-swim listed in the Manual. The thrust values used were obtained from Dr. Glen Egstrom of UCLA who is generally acknowledged to be the most active investigator in the field. The values obtained do fall within the range of those attributed to moderate exercise in the Manual. The 40°F values obtained increased slightly with duration; the slope shows an increase of 0.019 cfm per hour.

b. 60°F Dives

The rest and light exercise values were very close to those predicted in the Manual. The moderate exercise values were about 50 percent of those listed in the manual for 1.0-knot swim. Very little change in these rates with time was observed as is evident from the small values for the slopes. The 60°F water temperature appears to be the optimum condition for the wet suits used. All divers finished these dives, and the gas consumption rates were close to the predicted values in the Diving Gas Manual (Figure 6). It is interesting to note that less gas was used during moderate exercise at this temperature than for either of the other water temperatures.

c. 80°F Dives

Diver thermal insulation was reduced on these dives. Each diver selected the dress he considered most appropriate. Most divers wore ordinary 1/4-inch wet suit pants. One diver's legs were bare. Several divers wore 1/8-inch vests with hood so that their arms were bare. No shivering was observed, only small drops in rectal temperatures were noted, and the divers appeared comfortable.

The rest and light exercise values were quite close to those predicted by the Manual. The moderate exercise values were considerably higher than those found on the 60°F dives. They were even slightly higher than the 40°F dives. The cause of this is not known.

During the fourth hour, Diver F was aborted for high heart rate. He recovered without after effects and no cause for his problem could be determined.

PREDICTION EQUATION

A regression analysis was conducted on test data using the linear modeling technique of statistics. The following primary variables were studied in this analysis (see regression model in subsection Experiment Design):

Exercise, water temperature, divers' rectal temperature, respiratory rate, and time (in minutes)

Interaction variables were:

Water temperature/exercise

Water temperature/divers

Rectal temperature/time, and respiratory rate/exercise .

The analysis indicated that exercise, water temperature, and rectal temperature were the three primary independent variables. The correlation between respiratory rate and gas consumption rate was particularly good as was the correlation between respiratory rate and the independent variable exercise. However, it would not add a significant amount to the prediction capability (correlation between exercise and gas consumption was better than the correlation between respiratory rate and gas consumption). Time as an independent variable was not significant when the regression was obtained for all data combined. This was caused by gas consumption increasing with time in 40°F water and decreasing with time in 60°F water. Rectal temperature was correlative with water temperature and would not add a significant amount to the prediction capability. No interaction variables added significantly to the regression prediction equation.

Considering the information gathered during the tests it is valid to present only a gas consumption prediction equation for 40°F water. The test results showed (1) that the gas consumption in 60°F water for rest and light exercise compared favorably with that in the Diving Gas Manual; (2) there is some doubt whether or not the exercise on the ergometer simulated a 1-knot swim; and (3) a discrepancy in correlation of gas consumption with exercise and water temperature; i.e., gas consumption increased with time in 40°F water but decreased with time in 60°F water. Therefore, water temperature as a variable is deleted leaving exercise level and time as the two significant variables for the prediction equation. This equation, with a multiple correlation coefficient of 0.94 and a standard error of estimate of 0.077 cfm, is

$$\hat{\dot{V}} = 0.374 + 0.164 \cdot E_L + 0.488 \cdot E_M + 0.0006\ t$$

where

E_L = light exercise (E_L = 0 when not exercising and 1 when exercising)

E_M = moderate exercise (E_M = 0 when not exercising and 1 when exercising)

t = time in minutes.

NOTE: Rest in the equation is implied when $E_L = 0$ and $E_M = 0$.

This equation is plotted ($\dot{V}$ vs t) in Figure 11 along with the upper 90 percent confidence limit about the curve. This equation is based upon the experimental data of the test with the limited data base caused by only two of the six divers remaining in the 40°F water for the full 6-hour test.

DIVER THERMAL PROTECTION

Since only two of the six divers were able to proceed past the fourth hour of the 40°F dives, and considering the substantial increase in gas consumption rates observed, it must be concluded that the wet suits provide inadequate thermal protection. This view is supported by the diver's comments, the reductions in rectal temperatures, and the condition of the divers after the exposure. During most of the rewarm period, the men acted like "Zombies" in that they sat with head bowed, only reacted to direct requests, and had none of the cheerful bantering attitude seen during the other dives.

The suits appear to provide close to optimum protection for 60°F exposures, and would be expected to produce overheating in 80°F water.

REWARMING RESULTS

Historically, rewarming of divers exposed to cold water has involved the use of ambient heated air, hot showers, or immersion in hot water baths. Of these three methods, hot water immersion has proved to be the most effective. Under ideal conditions of hot water immersion, however, there is often a dangerous added drop of rectal temperature during the first half hour of the rewarm procedure. This temperature drop, which may reach 3.0°F, imposed on an already marginally chilled human body, might easily be a critical factor in initiation of a fatal condition of ventricular fibrillation. Because of this dramatic and dangerous situation, most investigators choose a core temperature cutoff point in the experiment to allow a safety margin of as much as 1.5°F continued drop during the first part of the rewarm period.

For the purpose of this experimental test series, it was considered unrealistic to use hot tub baths during rewarm because this would not be typical under operational conditions. Accordingly, after discussion with our consultant, Dr. Paul Webb, the judgment was made to use a rewarm technique proposed for the SEALAB III exercise, but never tested. Essentially, this involved introduction of hose-supplied hot water to

(Text Continued on Page 37)

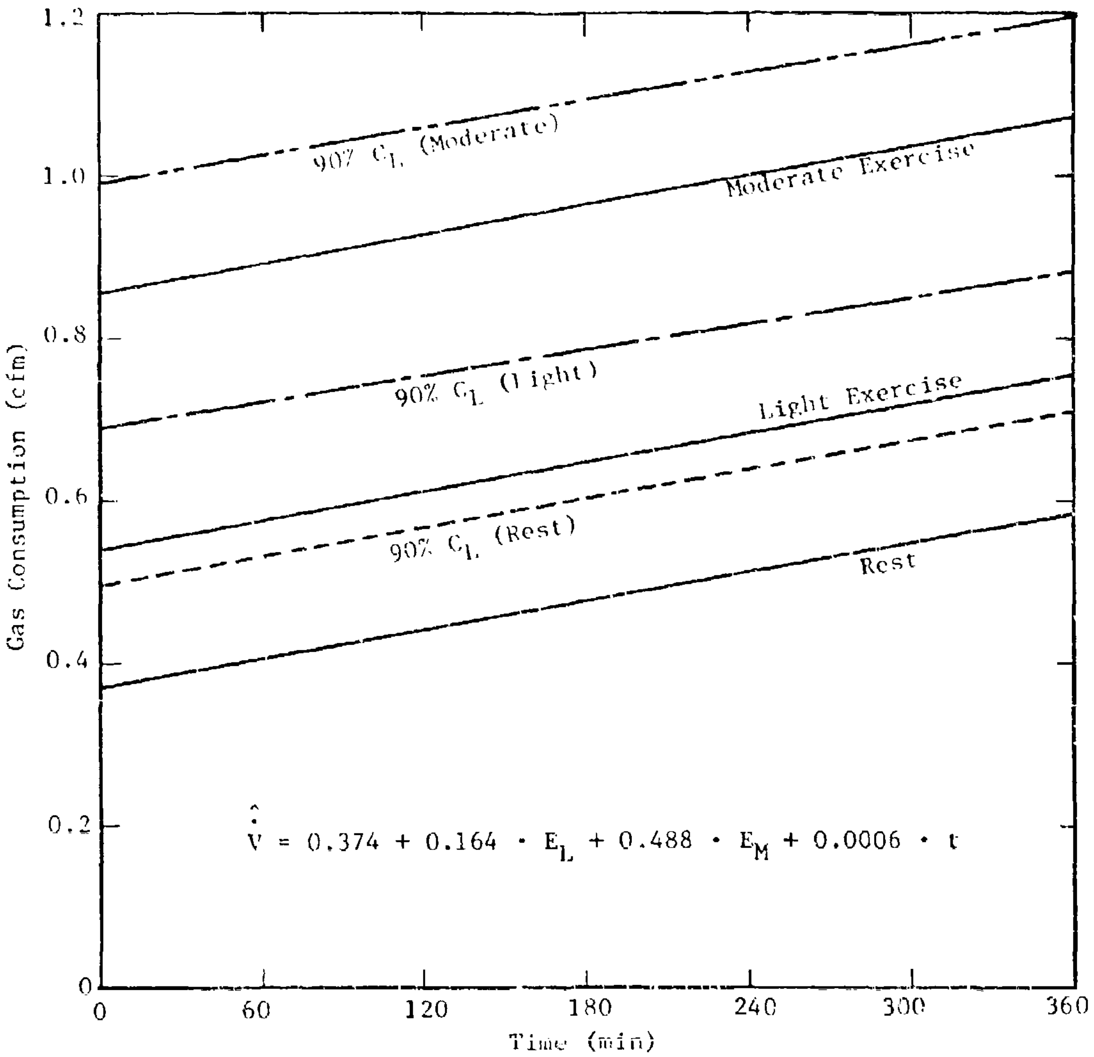

FIGURE 11. PREDICTED GAS CONSUMPTION IN 40°F WATER WITH 90 PERCENT CONFIDENCE LIMIT

the neck area of the body, beneath the wet suit worn during a cold water mission, without removal of the garment until rewarm was well established. This new technique, quite feasible for submarine application, was improvised with crude technology and employed with caution. The results were remarkable in that no diver showed a rewarm temperature drop in excess of 0.7°F, even after our most extreme exposures. Refinement of this rewarm technique will have important operational effects, and further work in this area deserves critical attention.

PHYSIOLOGICAL RESULTS

During the period of predive examinations each of the divers was found to be in excellent health and well conditioned, with average to above average pulmonary function. In all cases the lean to fat ratio, established by expert testing at the Naval Avaiation Medical Institute, Pensacola, was within normal limits with body fat percentages ranging from 12 to 21 percent. Likewise, the blood chemistries and morphologies were all found to be within normal limits in the predive baseline studies.

Immediately following rewarm recovery from dives 4, 5, and 6 (40°F), blood samples were drawn once more for comparison with baseline values. Aside from a consistent elevation of the stress enzymes, which was expected, no abnormal changes in blood chemistries were found. Judging from the relatively large percentage of aborts within the first four hours of cold exposure, and from the general physical appearance of the divers at termination of each individual 40°F dive, there was undoubtly a considerable degree of physical impairment in all divers in these tests. Full recovery without residual effects within 24 hours was evident in all cases.

CONCLUSIONS

1. The rest and light exercise gas consumption rates in 40°F water were substantially greater than those predicted from the U.S. Navy Diving Gas Manual and were found to increase with dive duration. The rates for the 60°F and 80°F dives were quite close to predicted. It appears that the demonstrated loss of thermal equilibrium in the 40°F water increased the consumption of breathing gas but no information was obtained which would justify the prediction of rates at temperatures between 40°F and 60°F.

2. The gas consumption rates for moderate exercise were less than predicted for a 1.0-knot swim for all water temperatures. It can be

concluded then that (a) the 12-pound thrust value used in this experiment was less than that required to simulate a 1.0-knot swim, or (b) the value given in the manual is too high. When the variations in the drag due to differences in diver size, shape, and equipment are considered, it becomes apparent that different thrust values would be necessary for each situation.

3. Since only two out of the six divers finished the 40°F dives, the confidence level of the results was less than for the other water temperatures. The confidence level could be improved by conducting more 40°F dives to establish a larger data base or, preferably, by improving diver thermal protection so that a majority of the divers complete the tests.

4. The technique of rewarming the divers by flooding the suit with hot water was found to be excellent.

5. Medically, no irreversible physiological damage was sustained by the divers during the experiment, although considerable physical deterioration was evident at the conclusion of the 40°F dives. Blood chemistries were essentially unchanged and electrocardiograms were normal throughout. Diver rewarm was considered a vital factor for the return of the divers to full physical capacity.

RECOMMENDATIONS

1. Repeat the 40°F dives using improved diver thermal protection. A constant volume dry suit is suggested. The suit should be equipped with a urine collection device so that diver urination does not degrade the thermal insulation of the dry suit. When adequate thermal protection is obtained at 40°F in the test tank, the depth variable should then be incorporated into the experiment and information obtained the depths pertinent to SDV missions.

2. A program to validate the diver rewarm technique for Fleet operational use should be undertaken. The simplicity of the procedures and equipment make it attractive even for application to nondiver situations such as cold exposure of personnel.

3. Since the wet suit used in the tests will continue to be used for temperatures below 60°F, gas consumption rates at water temperatures between 40°F and 60°F should be obtained so that the accuracy of gas consumption predictions can be improved.

4. An operational validation of the results obtained during these tests should be accomplished. The actual gas consumed by divers on an SDV mission should be measured and compared to that predicted from the results presented in this report.

5. The gas consumption of divers equipped for an SDV mission should be measured while actually swimming at 1.0 knot. The data obtained would improve estimates of gas consumption and range on actual missions.

APPENDIX A

GAS CONSUMPTION CURVES

This appendix contains the gas consumption curves versus time for all the dives. The curves are presented for each dive and diver, and include water temperature and exercise. On most of the curves the work periods and rest periods are easily recognized. Figure A10 is particularly interesting. Up to approximately 80 minutes, the consumption curve is typical for rest and work. Between 80 and 160 minutes the curve shows some deviation from the typical, while from 160 minutes to termination of the dive it is obvious that the diver is having problems. The diver was dizzy and nauseated and had a severe headache when the dive was terminated.

In most cases where the curve falls to zero consumption, it can be attributed to the diver surfacing for any of several reasons. In a few cases, zero consumption was indicated due to tape recorder problems. Causes for other curve anomalies have been indicated on the figures.

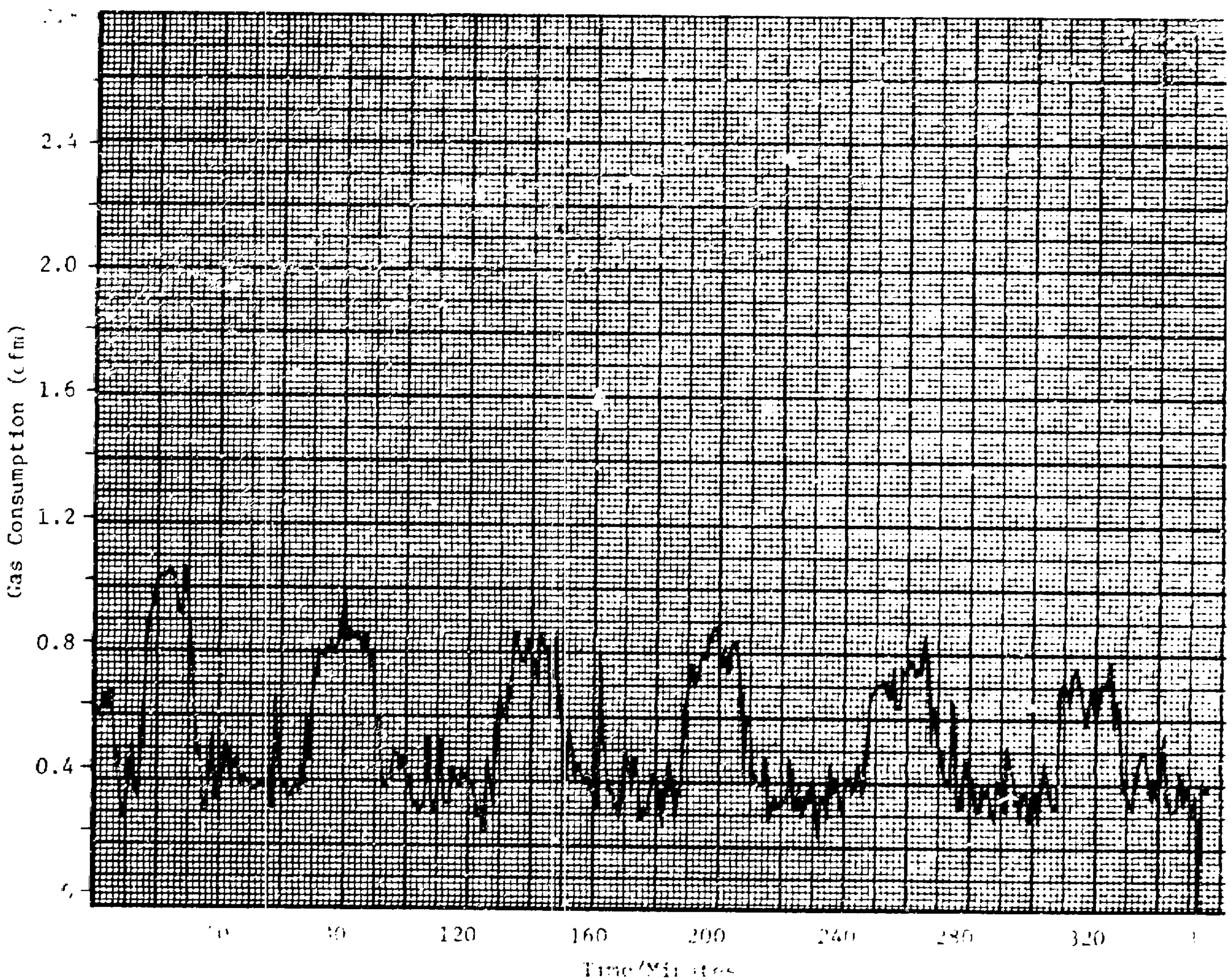

FIGURE A1. GAS CONSUMPTION VERSUS TIME, DIVE 1, DIVER B.
60°F WATER, MODERATE EXERCISE

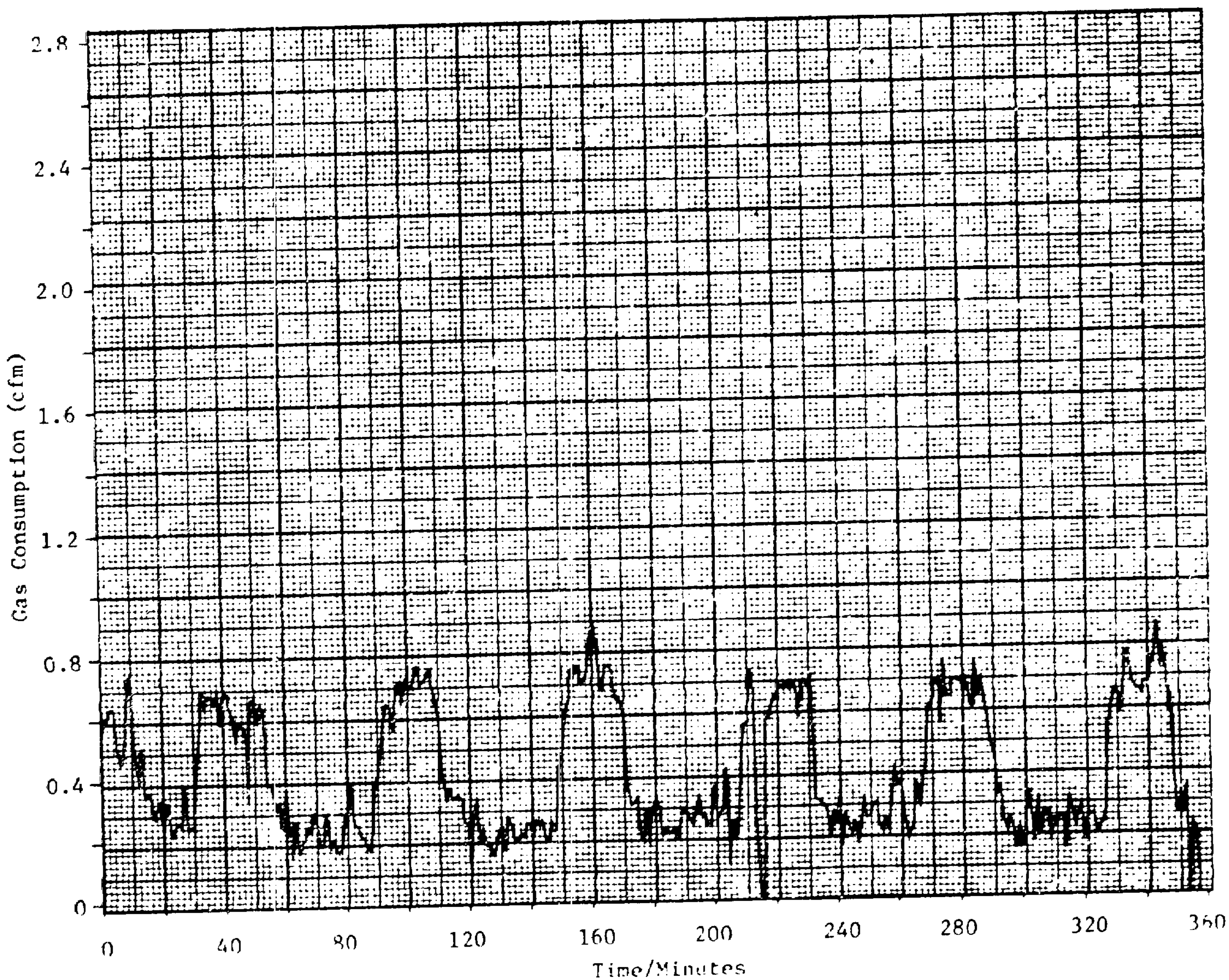

FIGURE A2. GAS CONSUMPTION VERSUS TIME, DIVE 1, DIVER E, 60°F WATER, MODERATE EXERCISE

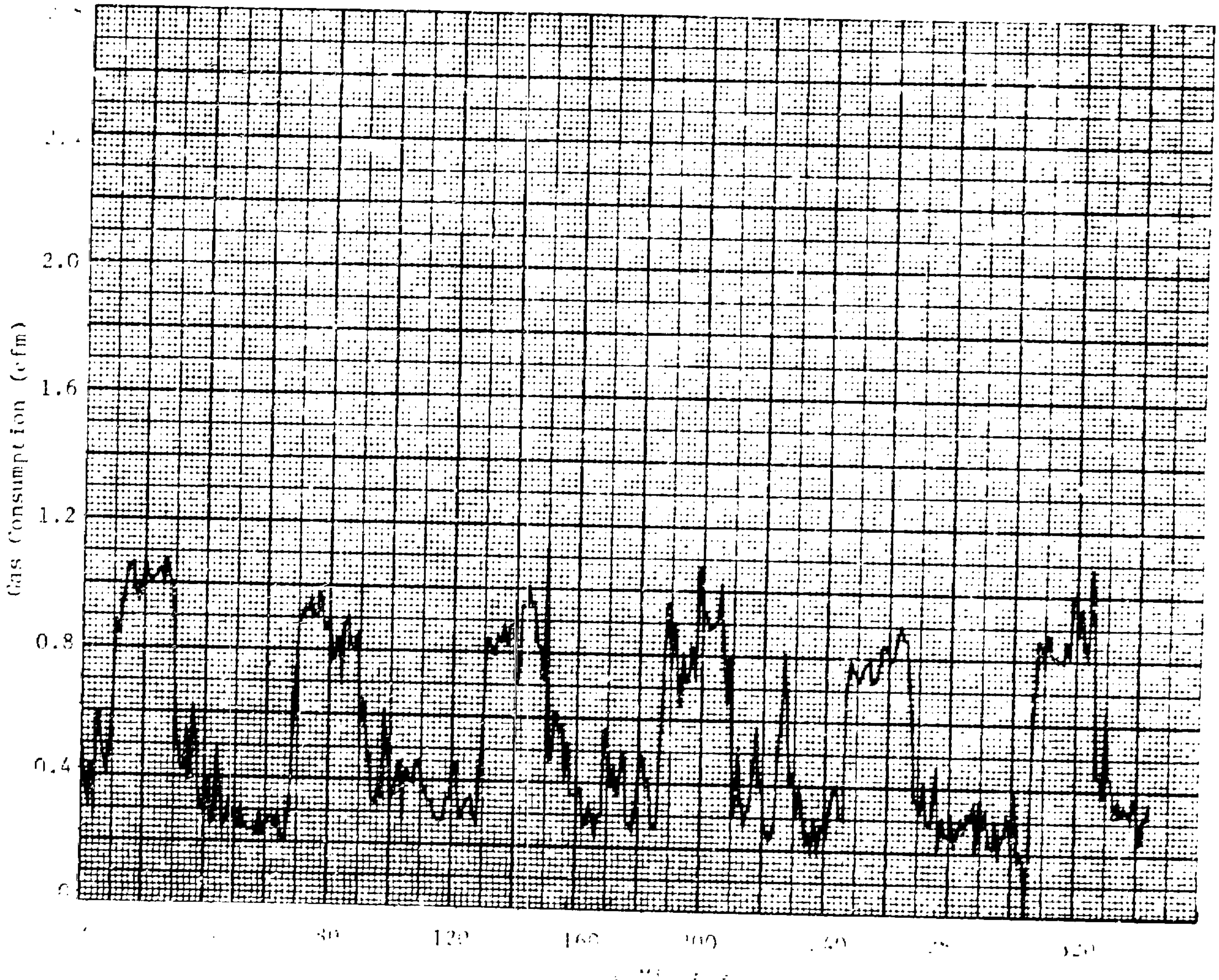

FIGURE A3. GAS CONSUMPTION VERSUS TIME, DIVE 2, DIVER A, 60°F WATER, LIGHT EXERCISE

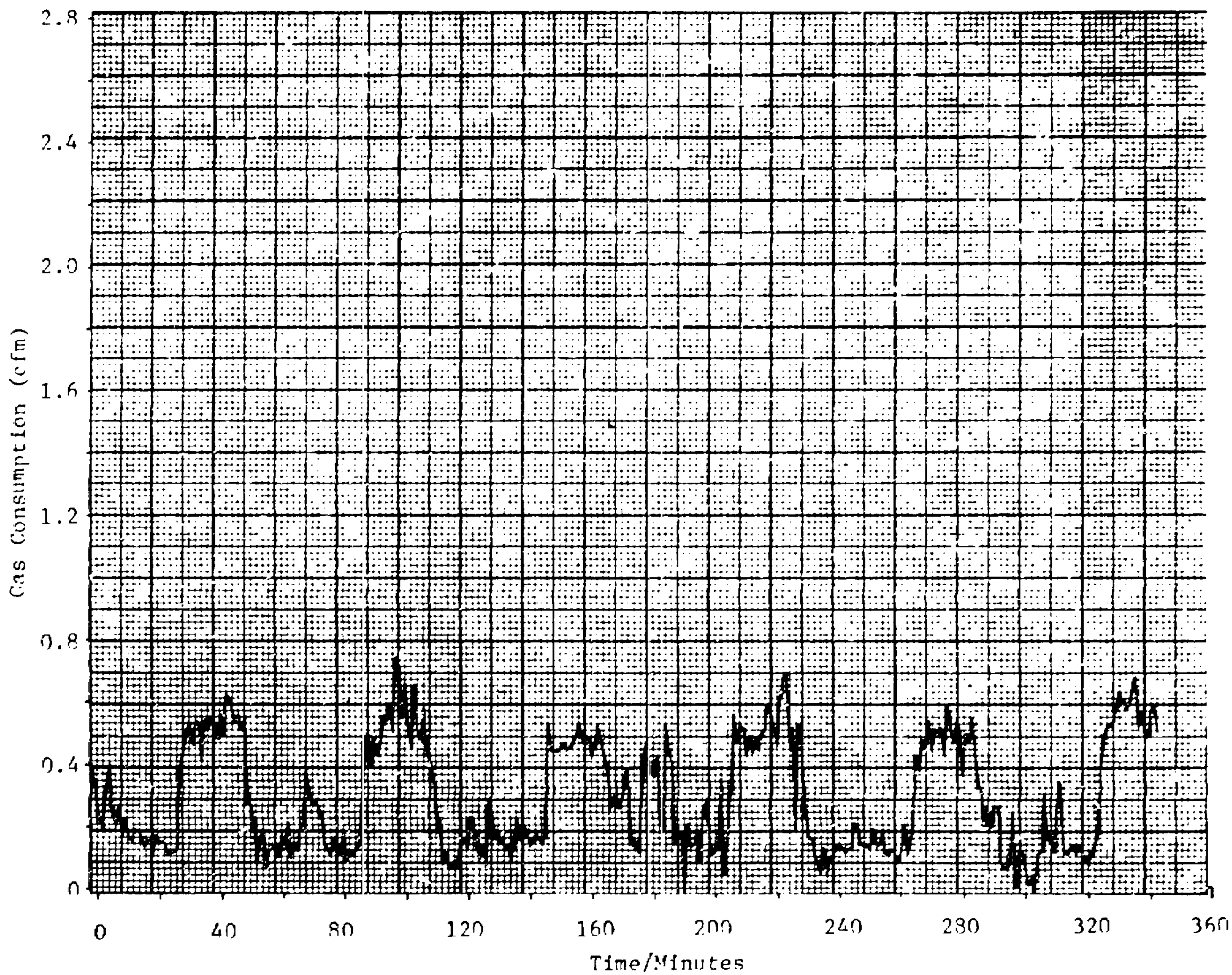

FIGURE A4. GAS CONSUMPTION VERSUS TIME, DIVE 2, DIVER F, 60°F WATER, LIGHT EXERCISE

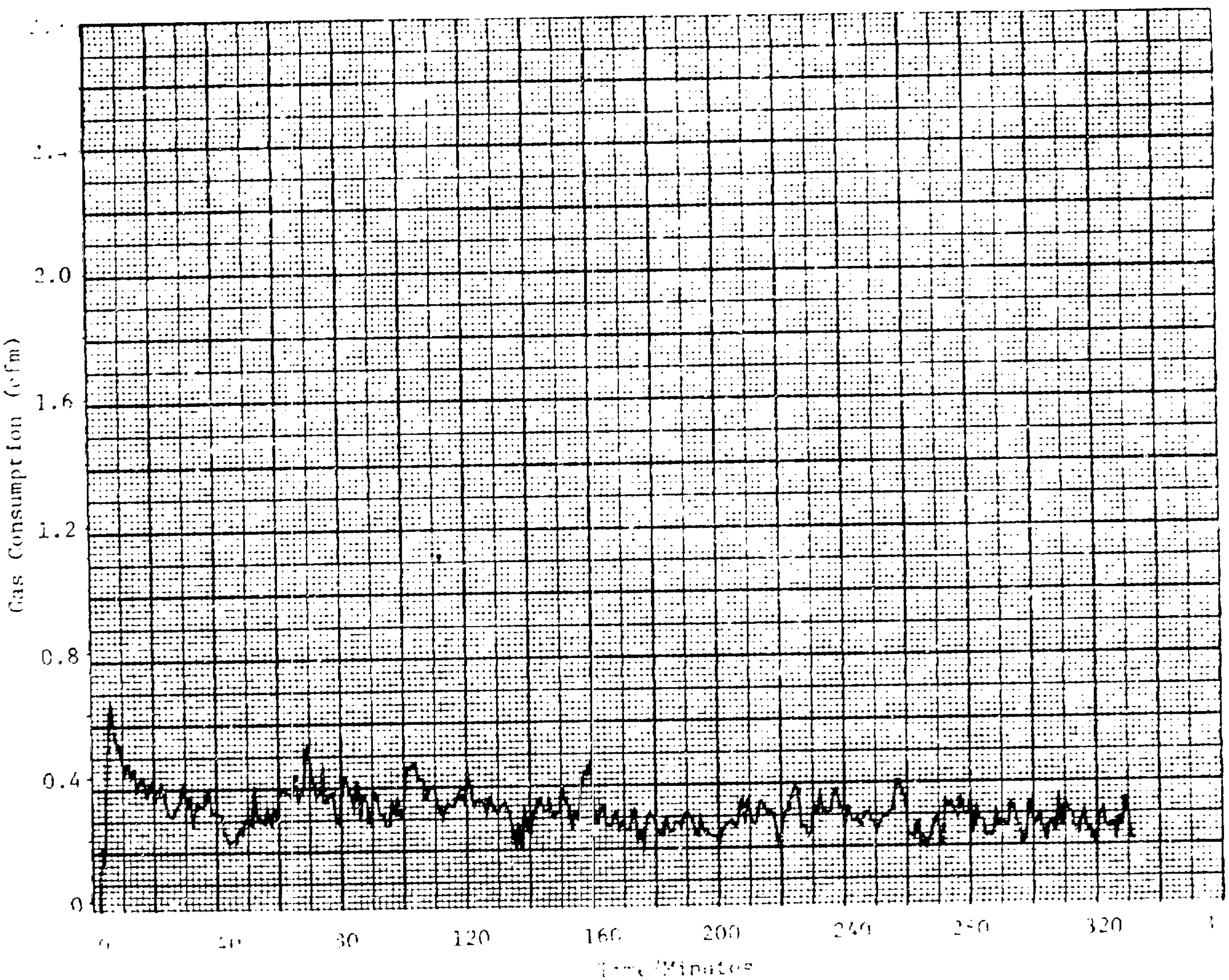

FIGURE A5. GAS CONSUMPTION VERSUS TIME, DIVE 3, DIVER C, 60°F WATER, REST

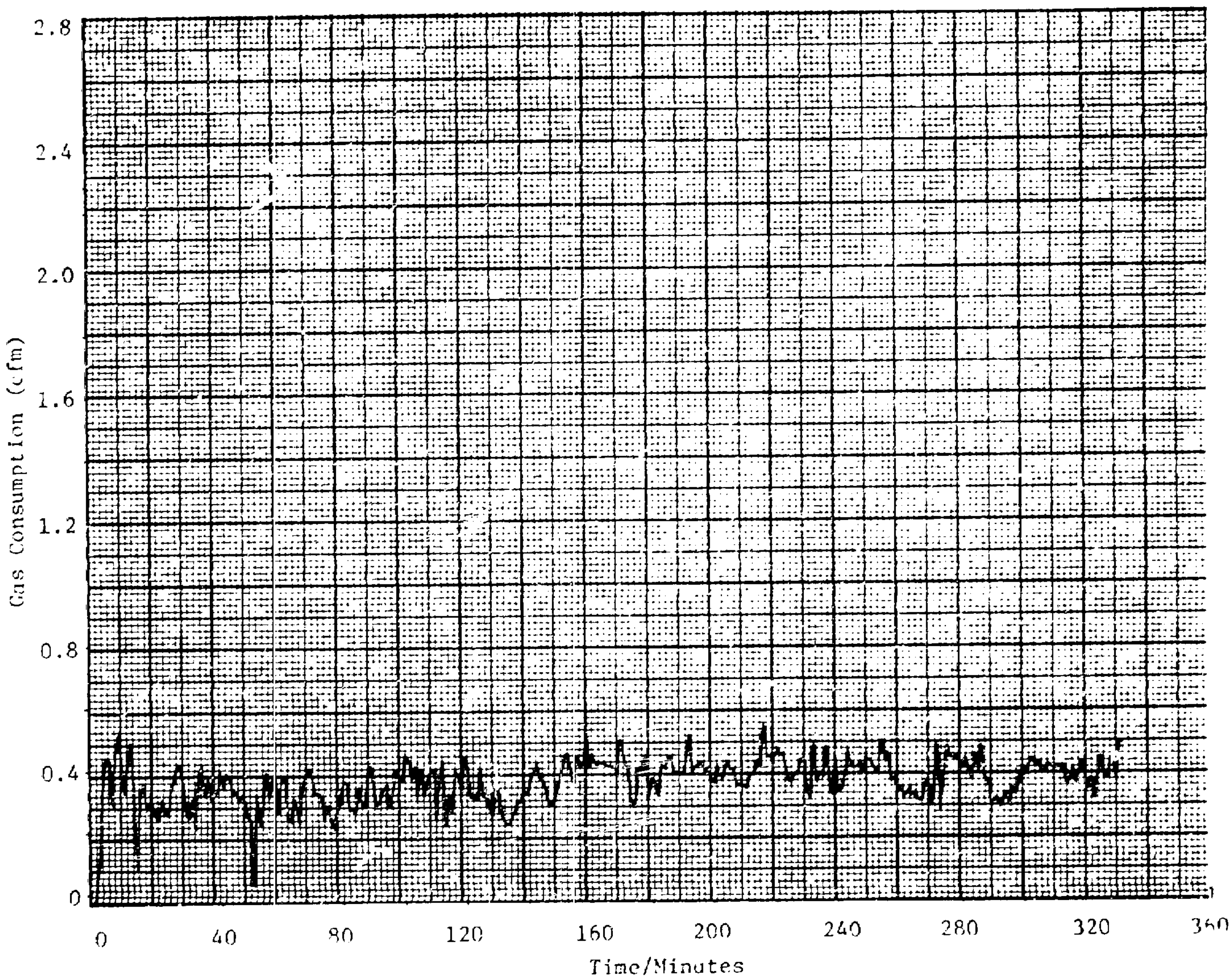

FIGURE A6. GAS CONSUMPTION VERSUS TIME, DIVE 3, DIVER D, 60°F WATER, REST

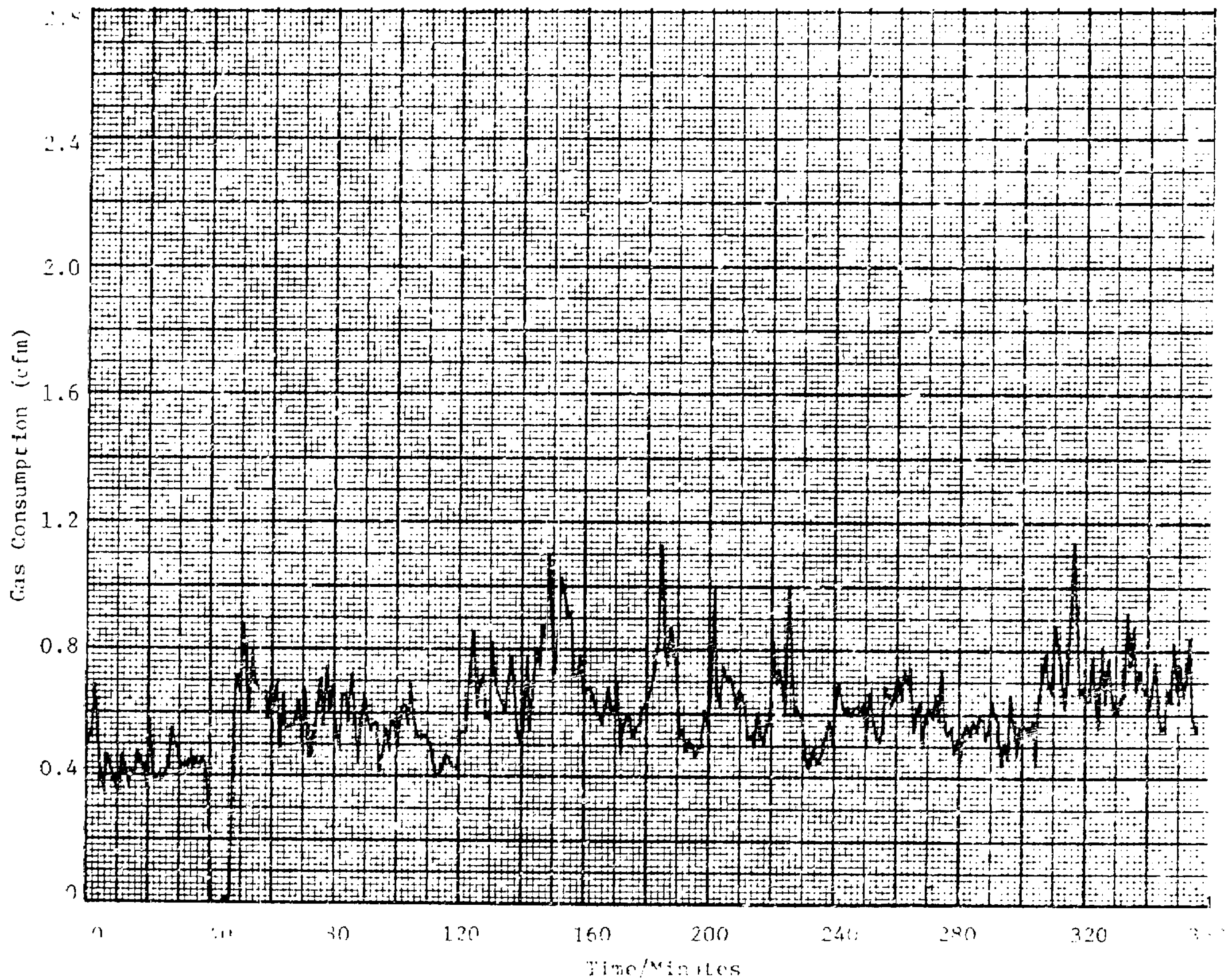

FIGURE A7. GAS CONSUMPTION VERSUS TIME, DIVE 4, DIVER A.
40°F WATER, REST

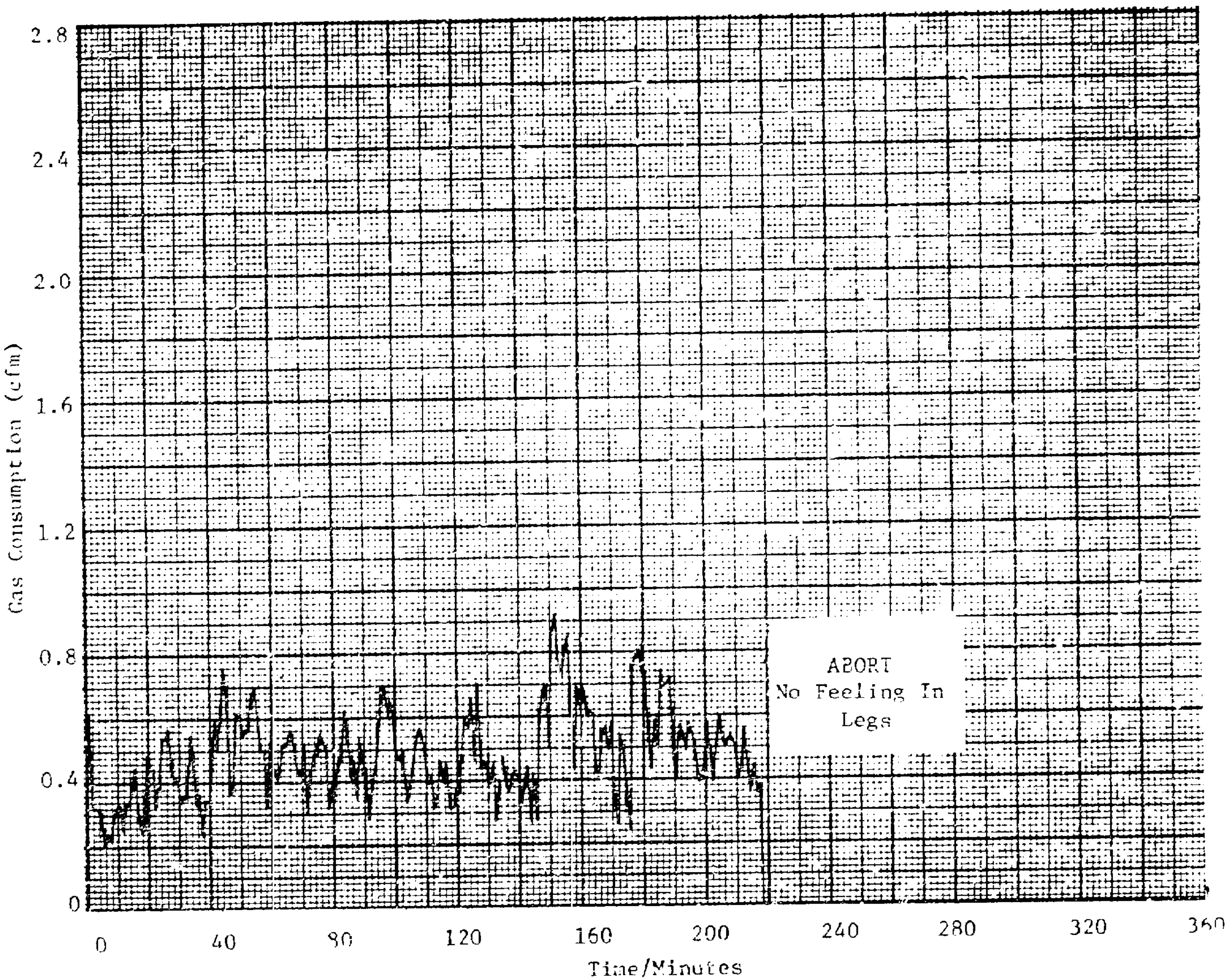

FIGURE A8. GAS CONSUMPTION VERSUS TIME, DIVE 4, DIVER F, 40°F WATER, REST

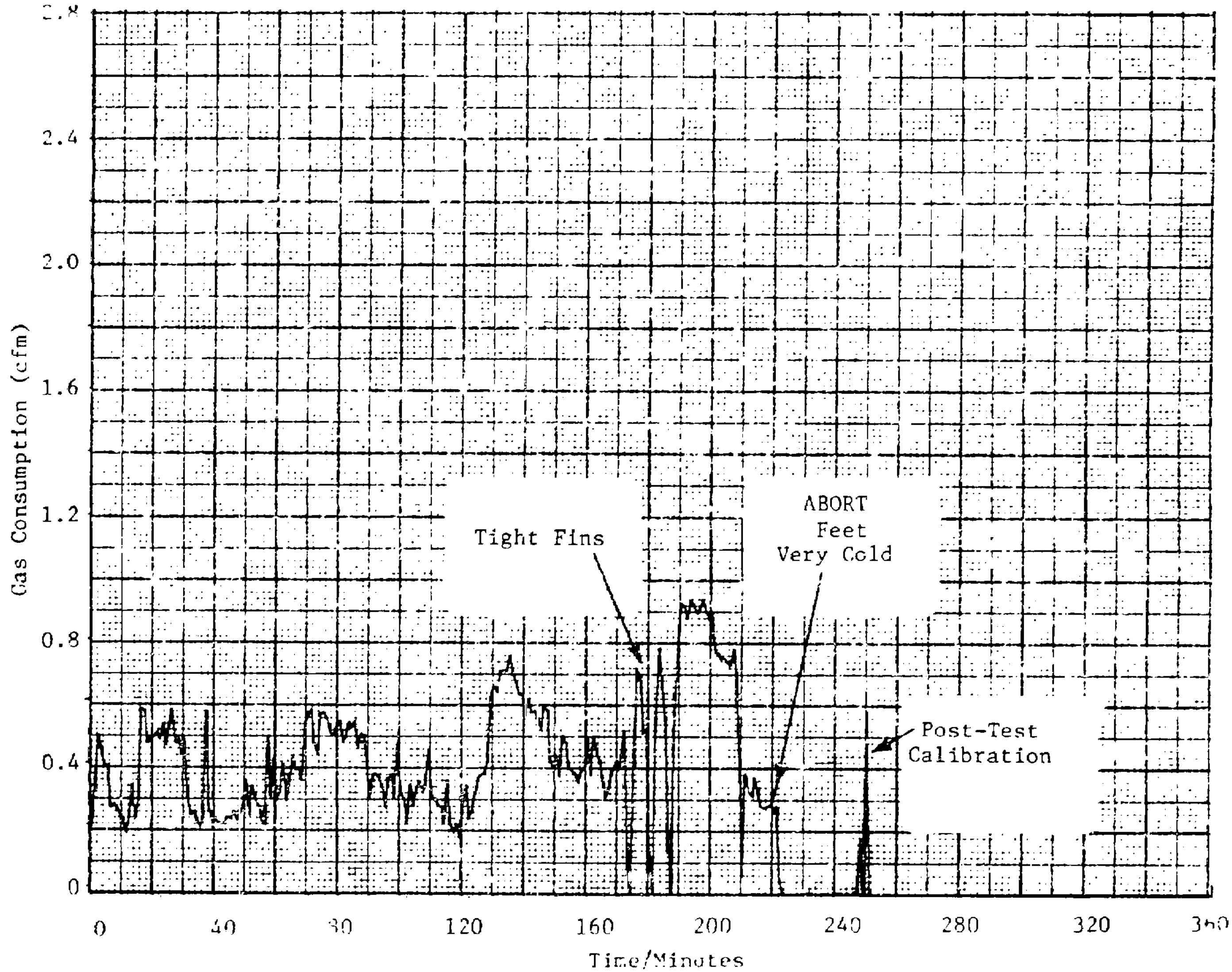

FIGURE A9. GAS CONSUMPTION VERSUS TIME, DIVE 5, DIVER B, 40°F WATER, LIGHT EXERCISE

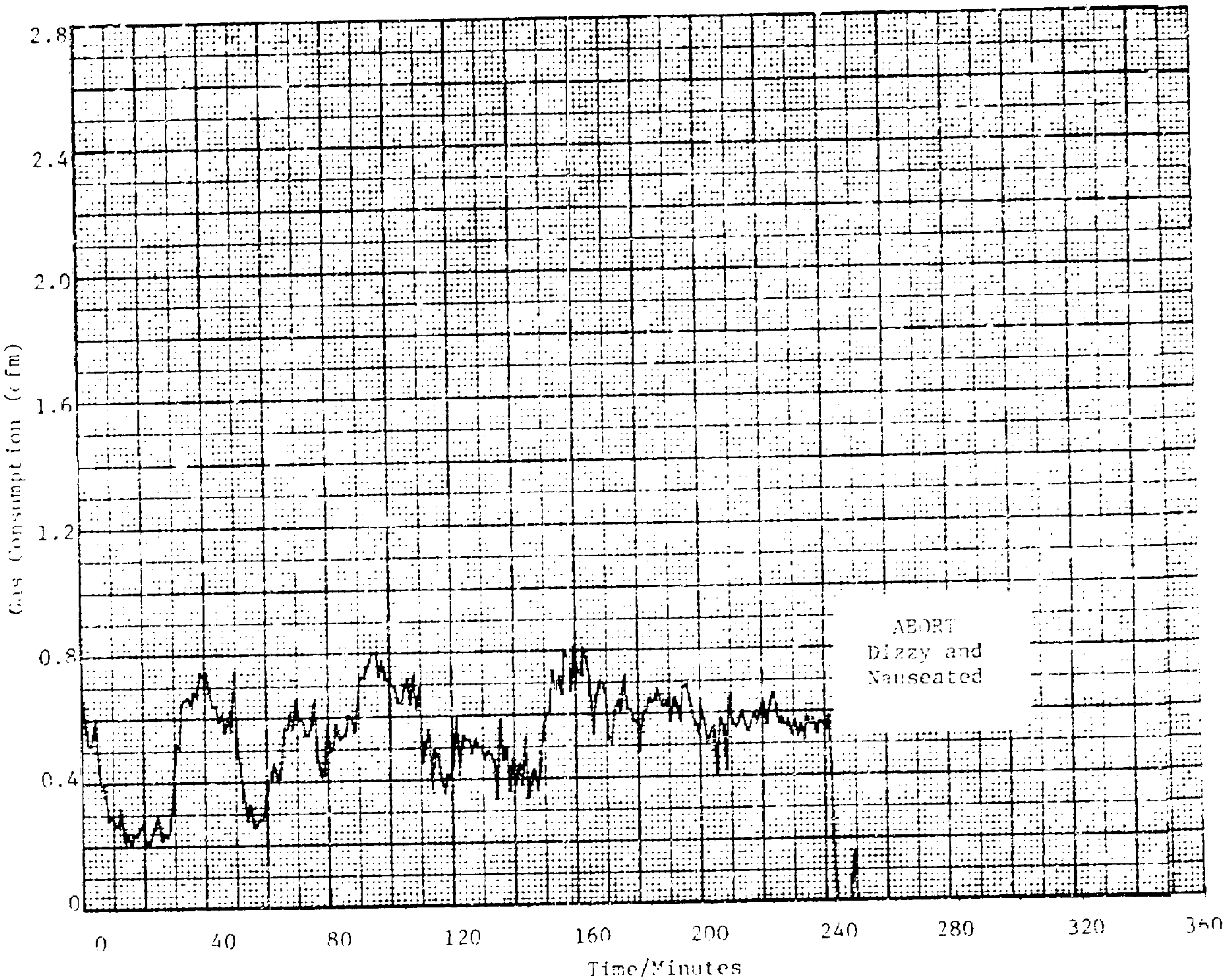

FIGURE A10. GAS CONSUMPTION VERSUS TIME, DIVE 5, DIVER E, 40°F WATER, LIGHT EXERCISE

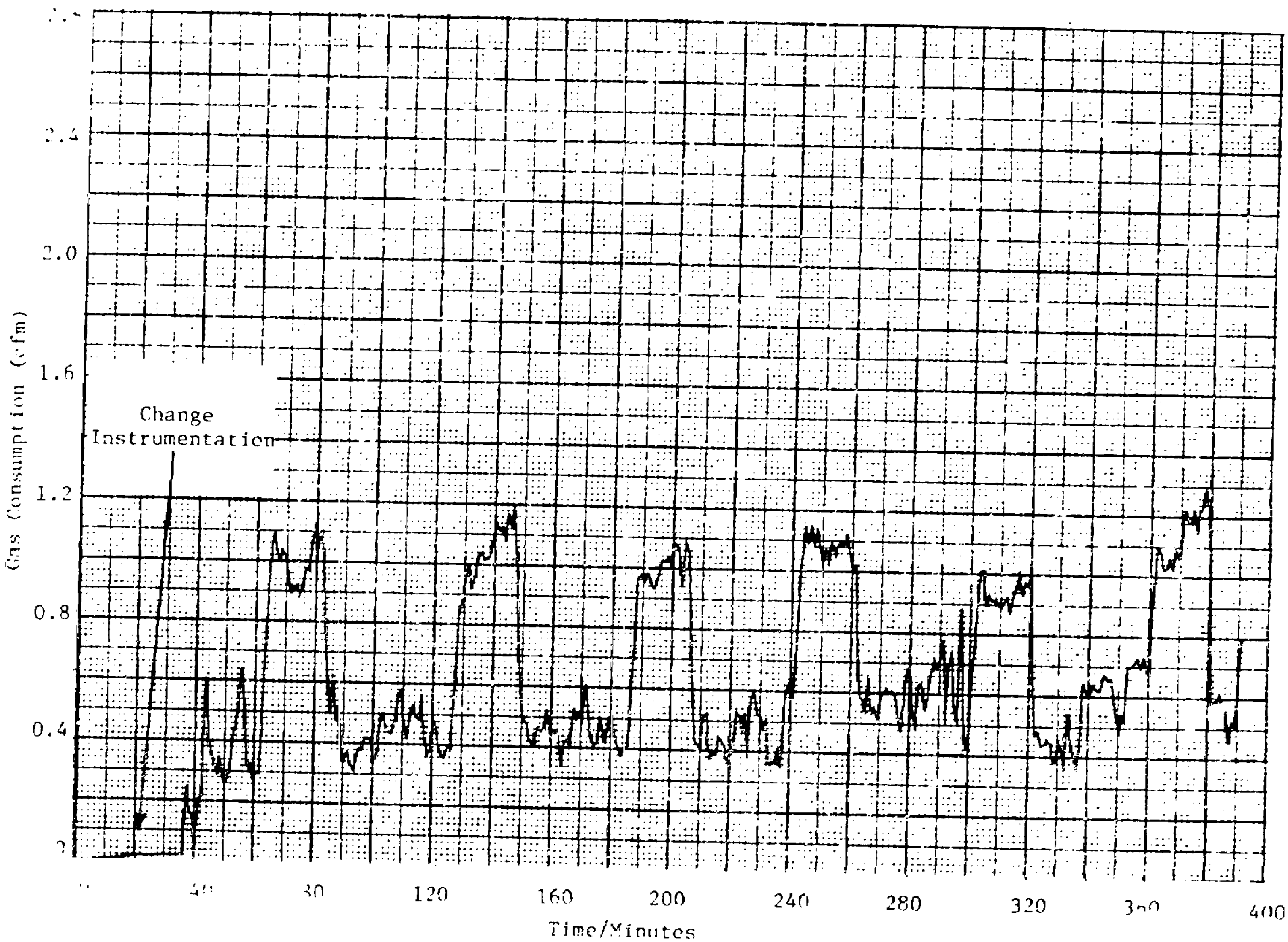

FIGURE A11. GAS CONSUMPTION VERSUS TIME, DIVE 6, DIVER C, 40°F WATER, MODERATE EXERCISE

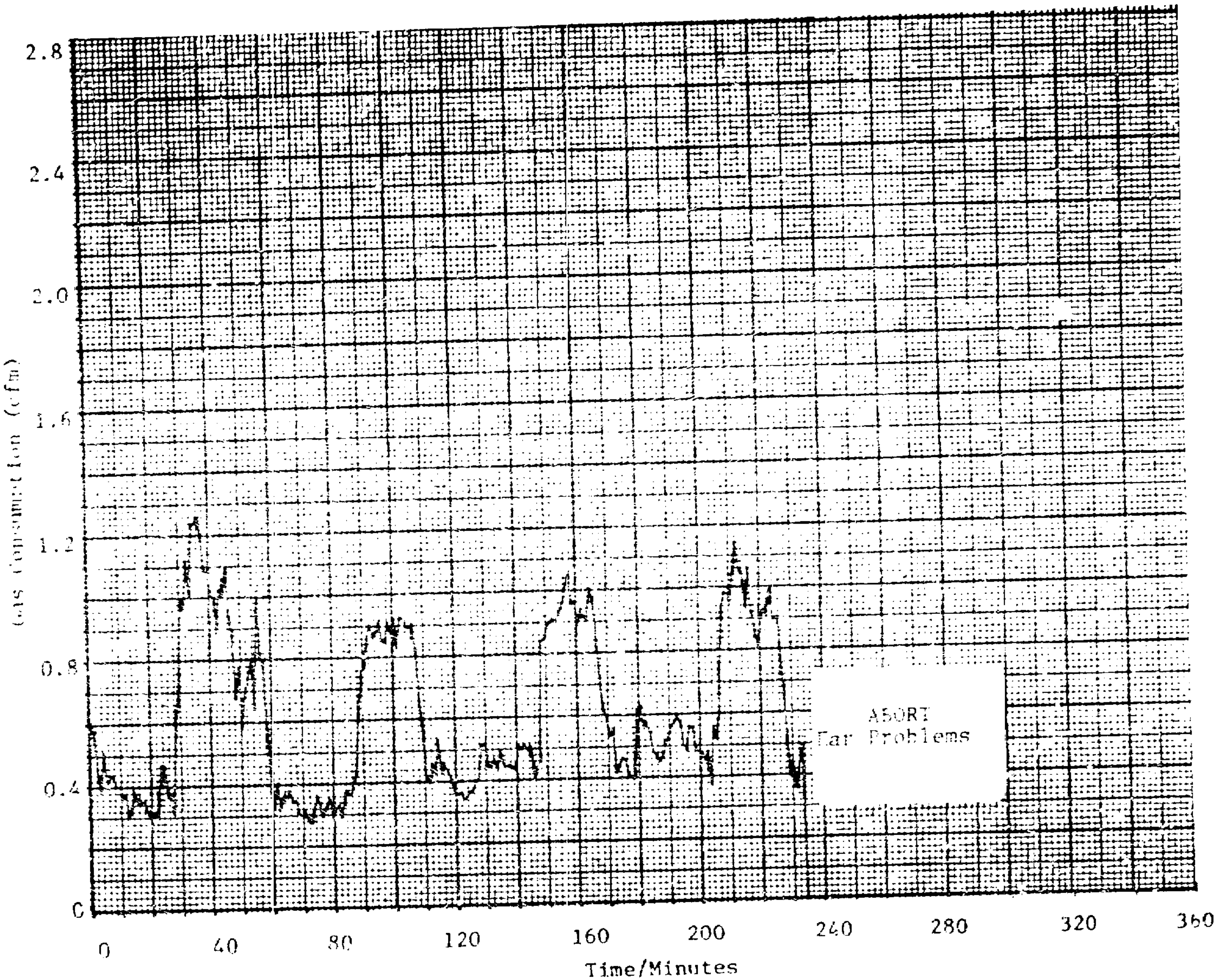

FIGURE A12. GAS CONSUMPTION VERSUS TIME, DIVE 6, DIVER D, 40°F WATER, MODERATE EXERCISE

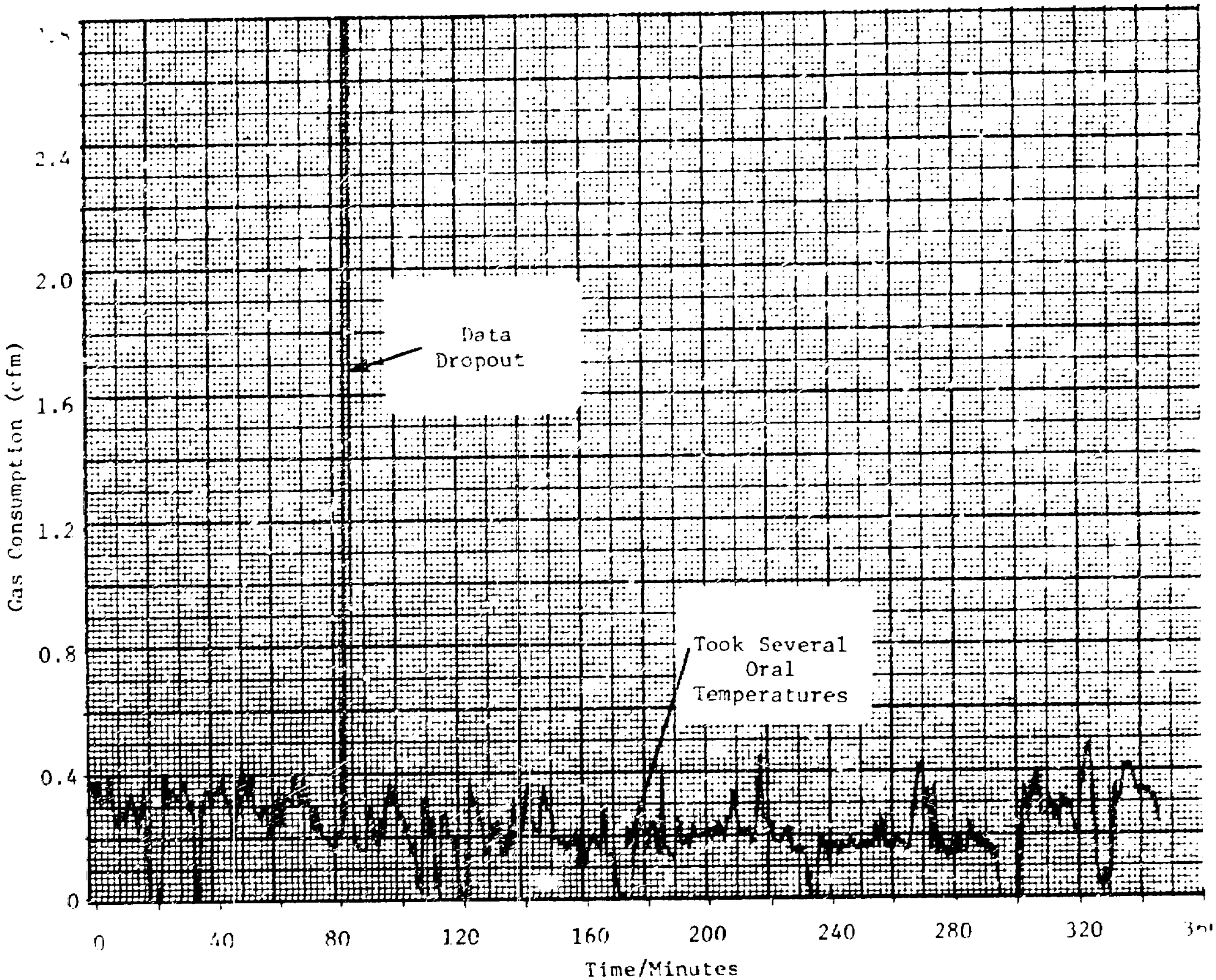

FIGURE A13. GAS CONSUMPTION VERSUS TIME, DIVE 7, DIVER B, 80°F WATER, REST

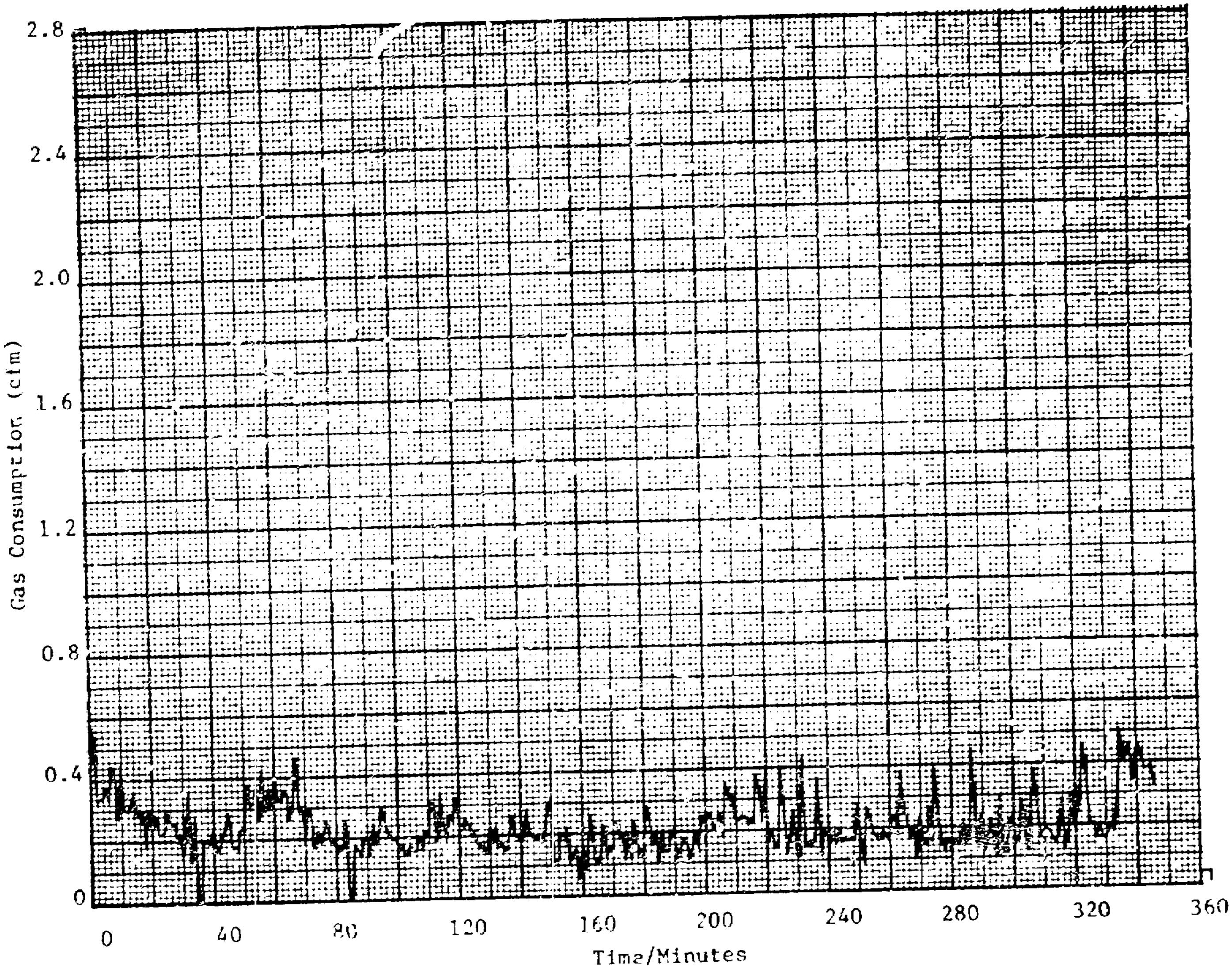

FIGURE A14. GAS CONSUMPTION VERSUS TIME, DIVE 7, DIVER E, 80°F WATER, REST

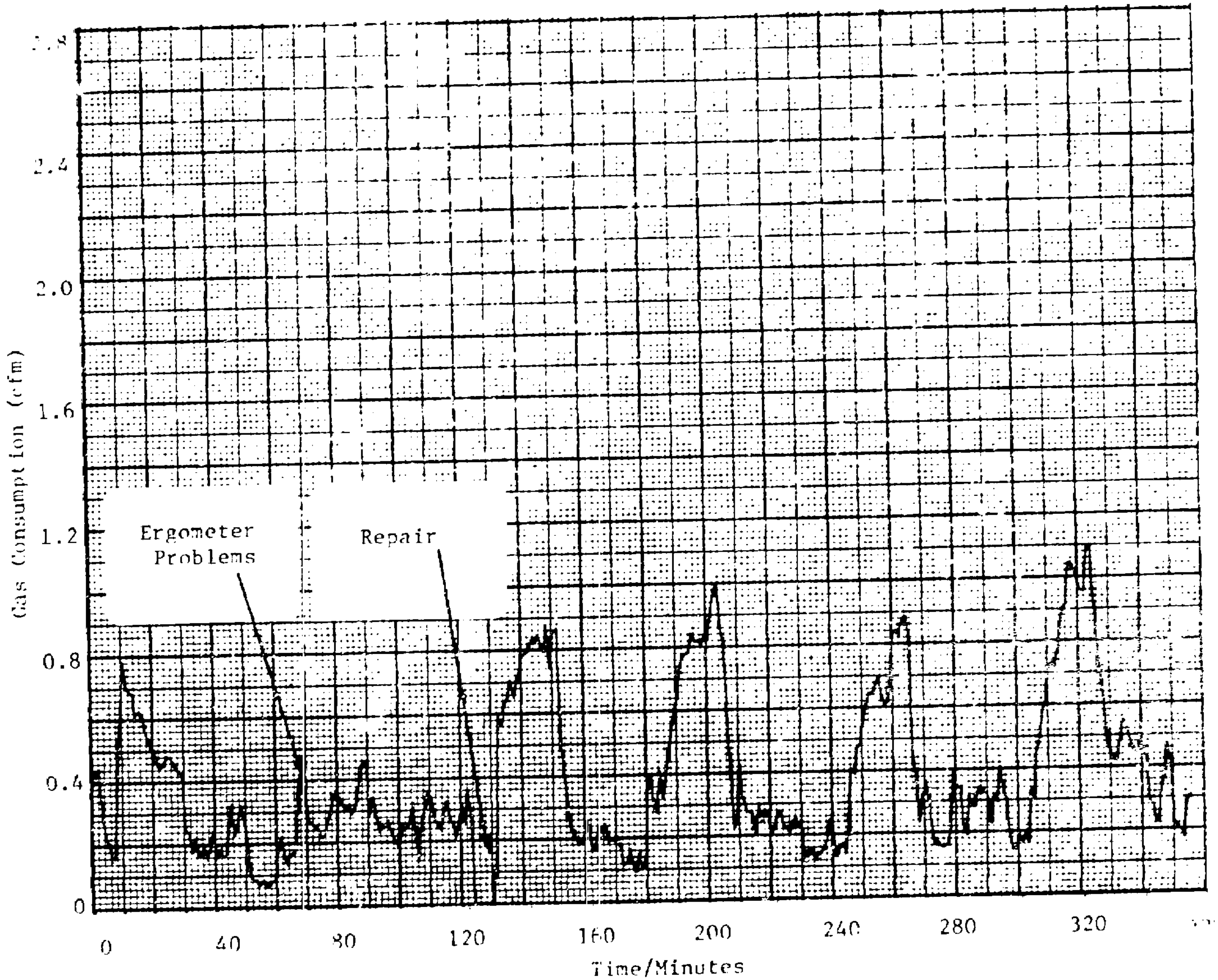

FIGURE A15. GAS CONSUMPTION VERSUS TIME, DIVE 8, DIVER C, 80°F WATER, LIGHT EXERCISE

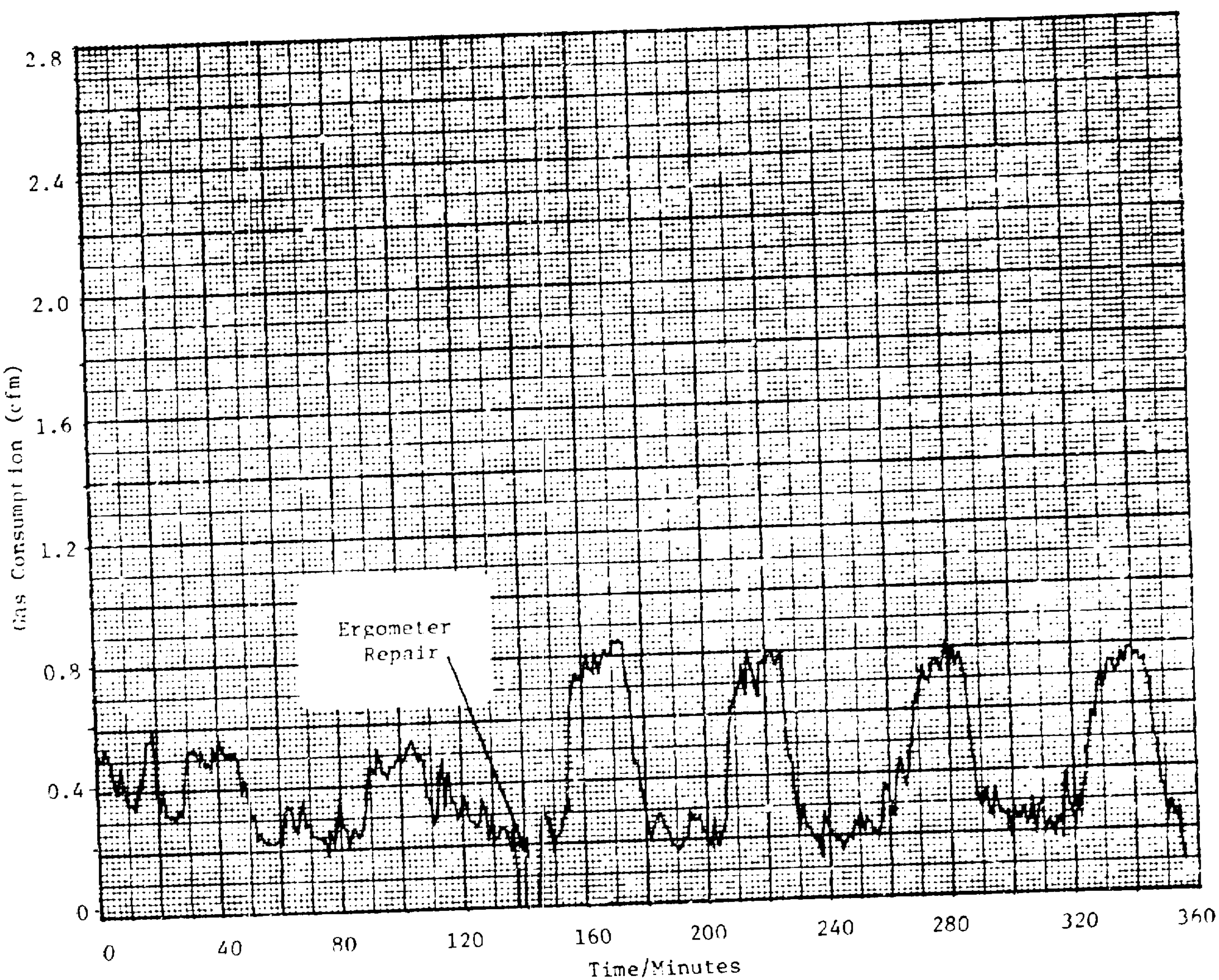

FIGURE A16. GAS CONSUMPTION VERSUS TIME, DIVE 8, DIVER D, 80°F WATER, LIGHT EXERCISE

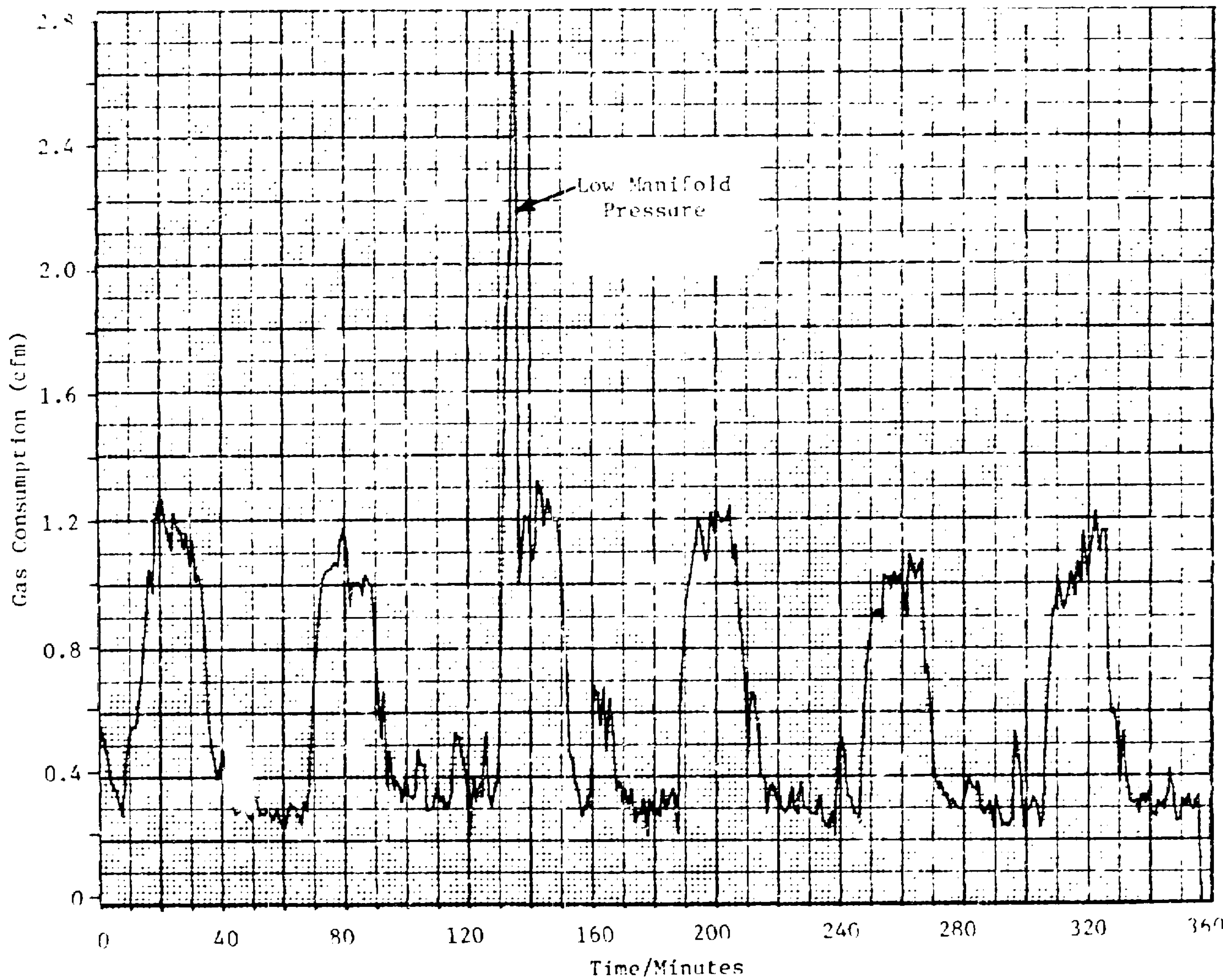

FIGURE A17. GAS CONSUMPTION VERSUS TIME, DIVE 9, DIVER A, 80°F WATER, MODERATE EXERCISE

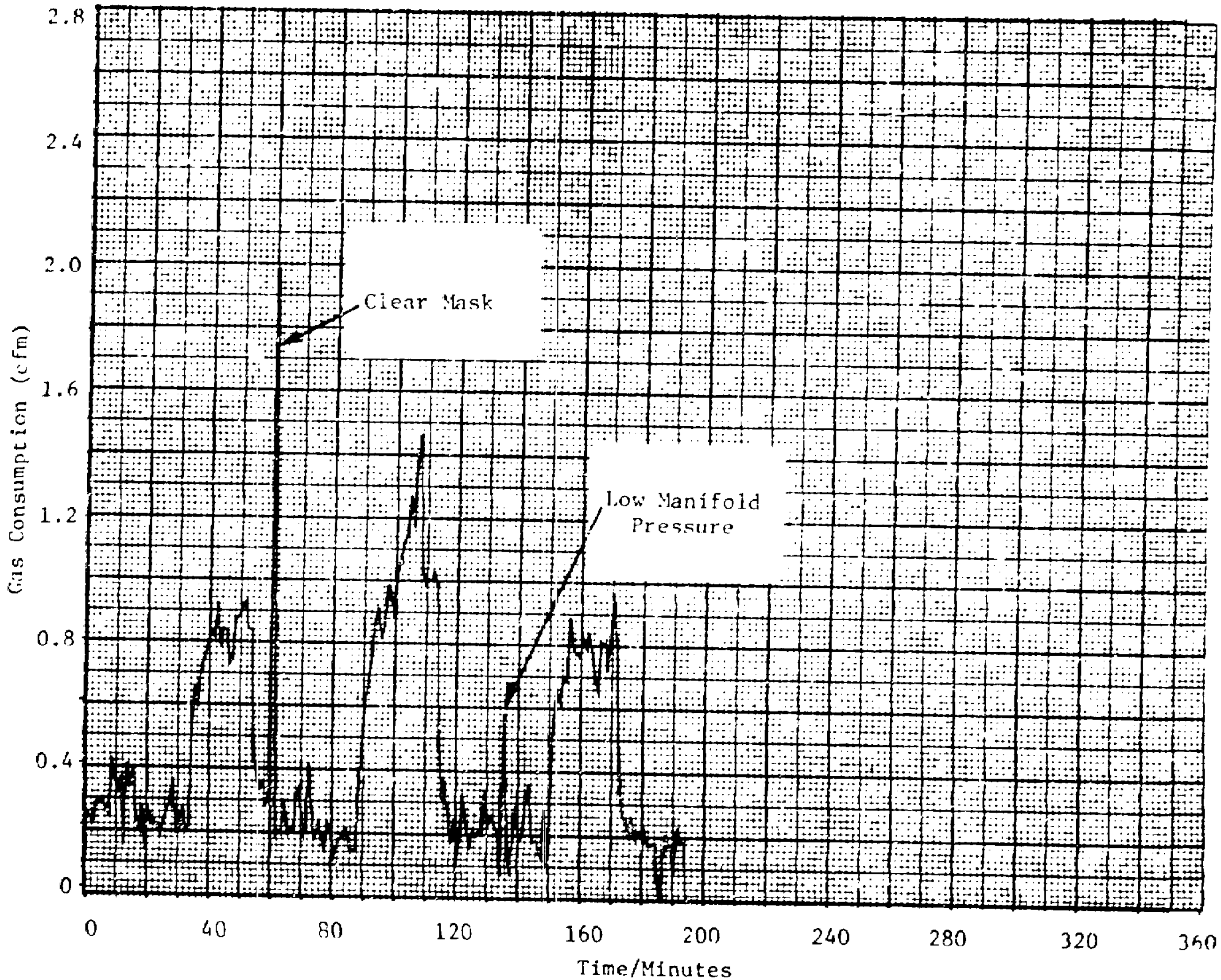

FIGURE A18. GAS CONSUMPTION VERSUS TIME, DIVE 9, DIVER F, 80°F WATER, MODERATE EXERCISE